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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal*, should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

Among papers to appear in forthcoming issues of the *Journal* are the following:

Pennsylvanian sedimentation in northeastern Socorro Co., New Mexico. By R. Sidwell and G. F. Warn.

Some occurrences of supergene iron sulphides in relation to their environments of deposition. By A. B. Edwards and G. Baker.

Longitudinal ripple marks in mud and sand. By L. M. J. U. Van Straaten.

A comparison chart for visual percentage estimation. By R. L. Folk.

The problem of dolomite formation considered in the light of research on dolomites in the Sonnwend-mountains (Tirol). By Robert Weynschenk.

Sea lions as geological agents. By C. A. Fleming. An unusual stalactite from Saltville, Virginia. By F. G. Snyder.

Gamma ferric oxide in sediments. By H. W. van der Marel.

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FIGS. 1–4, PLATES 1–2, DECEMBER, 1950

CONTRIBUTION TO THE SEDIMENTARY PETROLOGY OF THE SUNDA SHELF

F. A. VAN BAREN AND H. KIEL
Buitenzorg, Java

ABSTRACT

The literature relative to the geology of the Sunda Shelf is reviewed. Special attention is paid to Molengraaff's assumption that the bottom of the Sunda Sea is a drowned shelf. Samples of the bottom of this sea, collected during Termnavigations and already investigated by Mohr in 1918 on their mechanical composition, have been subjected to a sedimentary petrological analysis. This analysis has led to the separation of ten sedimentary petrological provinces. Along the shore of Sumatra and Java, next to recent volcanic deposits, ragged specimens of young augites, hypersthenes, and hornblendes of probable Tertiary age are found. Metamorphic andalusite and staurolite characterize the sediments along the coast of Borneo, whereas epidote and a blue-green hornblende are prominent in the South China Sea area. Malacca province is typified by a ragged hypersthene and is assumed to be closely related to the Pahang Volcanic Series of Malacca.

The boundaries of the geotectonic zones of van Bemmelen's "Kristallinicum" could be established with more detail. The existence of an anticlinal rift as the base of the coral reefs of Batavia Bay is made reasonably certain. Composition and areal distribution of the provinces led to a reconstruction of the geological history of the Sunda Sea in early Tertiary and late Pleistocene times.

INTRODUCTION

Dr. E. C. J. Mohr delivered a lecture "De sedimenten van de Java-Zee," in 1919 to the "Eerste Nederlandsch Indische Natuurwetenschappelijk Congres" at Batavia. Twenty years later the investigations begun by Dr. Mohr were resumed, with more modern methods.

Mohr's investigations began with a critical study of the origin and occurrence of the carbonate and marl soils of Java. The distribution of these soils raised a number of questions belonging in the domain of geology. The explanation of the occurrence of middle Miocene marls and late Miocene limestones containing quartz sands involved the problem of distribution of coarse and fine components. This problem led to an investigation of the geology of the shallow Java Sea and its apparently simple structure. The opportunity for this research was offered by the Termnavigations in the interest of hydrographic research in the Java Sea.

A series of samples of the bottom of the Java Sea was collected and given to the Laboratory for Soil Research in 1918 through the courtesy of Mr. van Weel, hydrographical assistant at the Laboratory of Marine Investigations. Dr. Mohr examined these samples by several methods. The mechanical composition and carbonate content were determined, and a simple mineralogical analysis was carried out in cooperation with his coworker, Dr. White.

The results of this investigation showed that no relation exists between the mechanical composition of the sediment and its location, and no connection between calcium carbonate content of the sediment and distance from shore or depth of water could be ascertained. It was established, however, that abundant quartz occurred in a large area around Borneo and Malacca, whereas sediments poor in quartz were found chiefly along the north coast of Java.

Mohr concluded that sea currents were not responsible for the distribution of these sediments. He pointed out that a strong current which comes from the southeast during the east monsoon would be expected to erode, or to prevent dep-

osition of, the smaller sized particles, leaving sand. The investigation showed, however, that the bottom area exposed to the current contained a heavy clay whereas sand bottom occurred in still water behind Banka. Mohr, following a lecture by Molengraaff in "de Koninklijke Academie van Wetenschappen te Amsterdam," in May, 1919, raised the question, is the bottom of the Java Sea an area formed by sedimentation or is it an old land surface modified by rising sea water?

The problem remained untouched for twenty years. Then, because of a problem which arose during a systematic mineralogical investigation of soils occurring along the north coast of Java, further work was done on the sea bottom samples. The soils had been found to contain some minerals whose presence was incompatible with the supposed origin in volcanic material to the south. The possibility of a source to the north, in the present Java Sea area, had to be considered.

The bottom material, which had been preserved in good condition, was investigated using the method developed by Edelman and his co-workers, the study of the heavy mineral fraction. This work was begun in 1938. It was interrupted by the war, but was later resumed and was completed in 1948.

GEOLOGICAL HISTORY OF THE SUNDA SHELF

Before discussing the results of the sedimentary petrological investigations, it is desirable to review briefly the geology of the area occupied by the Sunda Sea and the Straits of Malacca, from which the examined samples were derived (see pl. 1).

The Sunda Sea, which includes the Java Sea and the South China Sea, is characterized by its almost uniform shallow depth. Narrow tongue-shaped submarine inlets contain depths of more than 70 meters, but the depth generally does not exceed 40 to 50 meters (pl. 2). This vast shallow sea area has been named the "Sunda Shelf" by Molengraaff.

Molengraaff (1922) and Molengraaff and Weber (1919) consider the Sunda Shelf to be a peneplain, drowned at the end of the Pleistocene period, on which monadnocks remained to form archipelagoes such as Banka-Billiton, Lingga, and Riouw. The evidence for this concept is summarized in the following paragraphs.

The nearly plane shape of the bottom of the Sunda Sea has the appearance of a peneplain.

Vast areas of the coastal plain of East Sumatra are occupied by tidal forests. Some parts of the forest contain Nipa-palms and Rhizophoras and are always under water. Ebb and flow of the tide are observed tens of kilometers inland.

The rivers of the east coast of Sumatra and of the Banka, Lingga, and Riouw Archipelagos and also those of the south and west coasts of Borneo generally debouch into swampy estuaries. The funnel shaped mouths of the larger rivers of these areas are very striking. These morphological features are considered to be indications that the coast has subsided relative to the Sunda Sea.

Detrital tin ore is found near the south coast of Singkep, at Banka and at Billiton, in depths of 17 to 19 meters below present sea level. It is in front of the present river mouths and is covered by recent marine sediments. These occurrences suggest deposition at a time when the sea surface was at least some tens of meters lower.

Traces of old river channels in the surface of the Sunda Shelf were reconstructed by van Weel (1938) from sounding data (fig. 1). This reconstruction was practicable for the mud-free areas of the shelf, outside of the Java Sea, but it was not possible to recognize drowned valleys in the mud-bottom area of the Java Sea. Presumably the mud deposits would obscure any channels which had been present.

Fresh water fish faunas of the East Sumatra rivers and the Kapuas River in west Borneo were found by Weber to

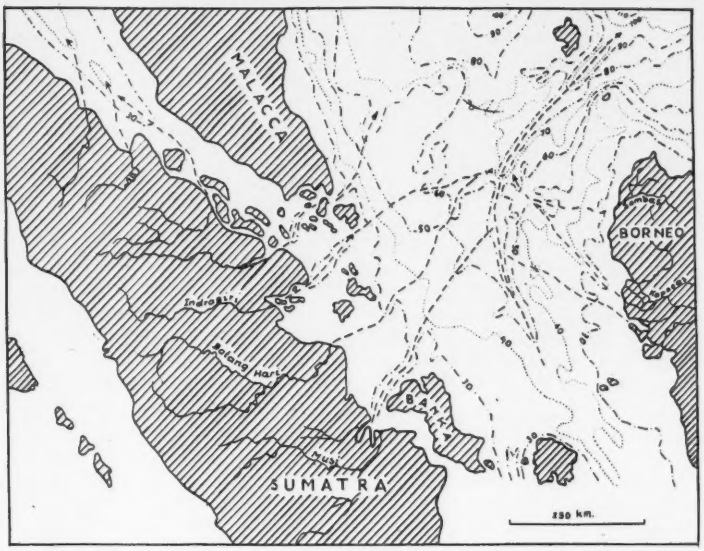


FIG. 1.

be closely related (Molengraaff and Weber, 1919), suggesting that the rivers of the two areas must have belonged to one river system. This system must be the Pleistocene river channels reconstructed by van Weel for the South China Sea, with the "North Sunda Stream" as principal river.

From the evidence summarized above Molengraaff has argued the possibility that the bottom of the Sunda Sea is a drowned shelf. He supposes, further, that the cause of the rise of sea level lies in the melting of the great ice-caps toward the end of the Pleistocene period. During the existence of the ice sheets the bottom of the Sunda Sea must have been above water and it must have been worn down to a low-lying surface of faint relief before the beginning of the latest glacial stage. Referring to Daly he supposes, finally, that the lowering of sea level in the Pleistocene must have been approximately 72 meters for the tropics.

Umbgrove (1929, p. 27) assumes that the Pleistocene coastline must be drawn at the present 100 meter isobath. A translation of his views follows:

> We hereby suppose with Molengraaff, that this area has maintained its stability since the beginning of the Pleistocene.
>
> Even the relief of the bottom of the South China Sea points to a conclusion in the same direction. In the South China Sea we also locate the deep channel (isobaths of 80 and 90 meters), which connects the valley-lines of the Sambas, Kapuas, Musi, Djambi and Indragiri [fig. 1], terminating near the isobath of 100 meters.

An old "Sunda Land" is envisioned, which includes the Sunda Shelf and its supposed monadnocks of the Banka-Billiton, Lingga, and Riouw Archipelagoes, the Malacca peninsula, some parts of East Sumatra, and west and central Borneo. Geological explorations on the land areas of this region have shown that they consist mainly of pre-Tertiary rocks.

The Sunda Shelf is regarded as the most extremely denudated part of the

old Sunda Land, which reached old age during the Pleistocene and was drowned at the end of the latest glacial stage. Quaternary detritus has been deposited subsequently along part of the coastal plain areas. (See pl. 2.)

During the Tertiary this part of the old continent supplied terrigenous constituents to the adjacent geosynclines of Sumatra, Java, and southeastern Borneo (Barito Basin), the "idiogeosynclines" of Umbgrove (1947, p. 50). Rutten (1927, pp. 104–105) has proved this convincingly for Java. His conclusions, based on petrographic investigations of young Tertiary sediments, are the following:

In north Java, from Batavia to Madura, the older rocks of the Neogene contain mainly detritus of "old rocks" as recognizable clastic material. The commonest mineral is rounded, dusty quartz; in addition, zircon, tourmaline, orthoclase, biotite, muscovite, andalusite, etc., are found; while "effusive" plagioclase, sanidine, hornblende, and augite are almost entirely mi[s]ing. In the same area the younger Neogene rocks contain rather much effusive material. The youngest Neogene rocks in North Rembang area consist entirely of tuffs, according to t'Hoen.

Towards the south in Java the size of the rounded "old minerals" seems to decrease, suggesting that their distributive province was to the north, in the domain of the present Java Sea. Furthermore, in southern Java effusive components come into prominence in the older Neogene rocks; in western Java the effusive material indicates the occurrence of rhyolites and dacites, rocks more acid than the present erupted andesites. It appears that volcanism began much earlier in southern Java—or perhaps in a more southern area—than in northern Java. The sediments of northern Java rich in quartz have a thickness of at least 1500 meters; it must be supposed that the area which supplied this quantity of sediment during the Neogene had vast dimensions in a horizontal as well as a vertical direction. We have localized that old continent in the Java Sea.

From mineralogical investigations of weathered Tertiary sediments from the geosynclines of Sumatra and Borneo, it appears that the source of the terrigenous constituents was in a land area between the geosynclines. In the Djambi region of Sumatra, for instance, the Tertiary sediments contain, in the upper horizons of the Palembang beds, the same monotonous mineralogical composition found in the Banka-Billiton group sandstone to the north (see "Results of the Sedimentary Petrological Investigation," below). It appears that the coarser clastic materials which are very rich in tourmaline were deposited near the coast in Tertiary time, while the finer-grained sediments rich in zircon were deposited in the deeper regions of the idiogeosynclines (or at a greater distance from the coast). In the Barito Basin of Borneo older and middle Tertiary sediments contain the tourmaline-zircon-rutile association, like that of Sumatra, and apparently it was derived from the pre-Tertiary acidic rocks of the old Sunda continent.

In conclusion from the evidence presented, it appears that in the Tertiary the detritus reaching the geosynclines was derived initially only from the old land mass bounded by the geosynclines. It is likely that the upper reaches of the Tertiary rivers had reached an old divide extending through the Malacca-Riouw-Lingga-Banka-Billiton islands by Pliocene time. Tertiary denudation will have occurred likewise in the vast area of the South China Sea. It is supposed that a Tertiary North Sunda stream existed there, and that its headwaters were at the previously mentioned divide to the south.

From the results of the sedimentary petrological investigation reported in following pages, it appears that the deposits found in the South China Sea were transported only a very short distance from their source in pre-Tertiary rocks. The boundary lines of the regional distribution of the mineralogical provinces described may be considered strike lines.

Van Bemmelen (1939) and Zeijlmans van Emmichoven (1939) have investi-

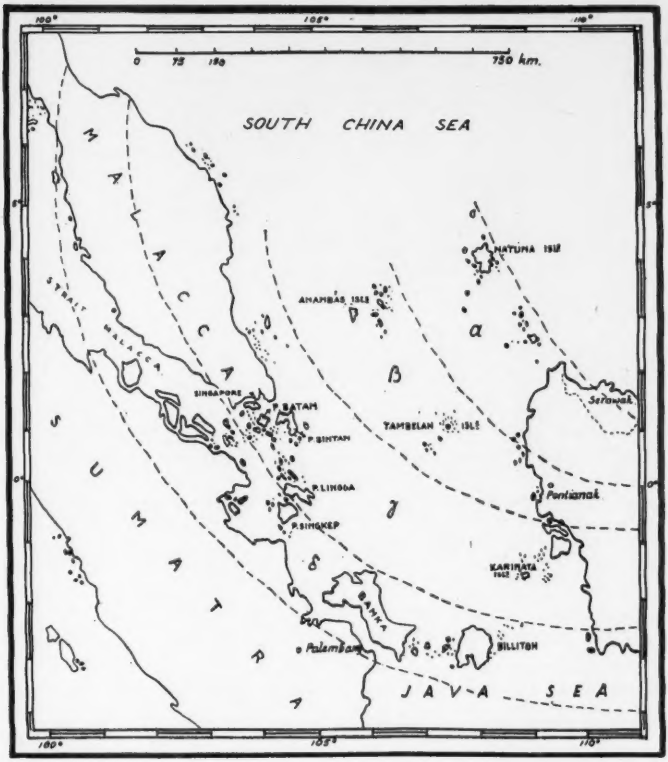


FIG. 2.

gated geologically the "Kristallinicum" of Borneo, which forms part of the old Sunda continent. By "Kristallinicum" is understood a complex geological unit composed of mainly acidic plutonic rocks, regional metamorphic, contact metamorphic, and dynamic metamorphic rocks. The dynamic metamorphic rocks are altered for the greater part by contact metamorphism. The "Kristallinicum" of west Borneo further forms the eastern part of the continental Sunda region, whereas the western part of this continent is occupied by the Malacca peninsula. By comparing the geological records of Scrivenor (1931) and those of Zwierzyncki (1929 a, 1929 b) with their own results, van Bemmelen and Zeijlmans van Emmichoven have indicated the supposed distribution of their geotectonic zones in the Sunda Sea (fig. 2).

In regard to the distribution of the geotectonic zones, van Bemmelen says the following (1939, p. 305):

> The continuation of the northern region of the Kristallinicum of west Borneo probably lies in the Natuna Islands (zone α); continuation of the Schwaner range zone may be situated in the Tambelan Islands and the Anambas-Group (zone β); and continuation of the southern region extends over the Karimata Islands to Lingga, to Bintan, Batam, and Singapore to the eastern part of Malacca with the

Pahang Volcanic Series (zone γ). Finally, a fourth zone, which is the most important producer of tin ore, may be distinguished southwest of zone γ. The fourth zone extends over western Malacca, over the southwestern part of the Riouw Archipelago and Singkep, and over Banka and Billiton (zone δ).

It will appear, however, that these boundary lines of the geotectonic zones in the area of the Sunda Sea do not coincide with the boundary lines (lines of strike) of the mineralogical provinces as established by the present sedimentary petrological investigation.

RESULTS OF THE SEDIMENTARY PETROLOGICAL INVESTIGATION

The method applied for this investigation originated with C. H. Edelman (1933) and the contemplations are based on the definitions introduced by him. For the sake of completeness, these last may be mentioned further.

Petrological Provinces and their Properties

Edelman (1933) and Edelman and Doeglas (1933, 1938) define a "detrital sediment as an association of detrital minerals and rock fragments." A "sedimentary petrological province" is a complex of sediments, i.e., of associations of detrital minerals, which by their distribution, age, and origin form a natural unit. "Distribution and age refer to the situation of the association of detrital minerals in space and time."

They have proved at the same time, that the mutual proportion of the detrital minerals belonging to the same sedimentary petrological province is never constant. These fluctuations are either a) accidental deviations, or b) variations logically founded.

The accidental deviations are controlled by the law of probability. The greater the deviation the smaller the probability of occurrence. The larger the number of observations, the greater the chance to meet such greater deviations.

The logically founded variations are mainly a result of selective sedimentation caused by the medium transporting the material. It is difficult to determine this influence quantitatively as the primary grain size of the different minerals in the parent rocks generally is not known.

For the interpretation of the results Edelman and Doeglas do not distinquish between the variations caused by outwash and the deviations checked by the law of probability. Both these deviations are, for the investigator, "chance variations." They may be considerable and only an extensive net of observations can give a good picture of these differences in the proportional content of the detrital minerals.

As long as there is no change in the origin and supply of the detrital material, the composition of the sediment will remain the same over the whole extension of a province, apart from chance variations. However, if any change should occur in the supply of material, then most likely another association of minerals will be deposited. The new association, therefore, will settle on the former resulting in the formation of a transition zone. Stratigraphically this zone finally will be succeeded by the new association. Edelman and Doeglas call these changes "normal changes," which eventually will characterize the whole area of the province.

The petrological "abnormal changes" are distinct deviations which are encountered in regions where sediments of different mineralogical composition are transported from two or more directions and meet and form mixed deposits. Due to this feature a certain location can belong alternatingly to the sphere of influence of two or more distributive sources. Seen in section the typical associations of the different deposits will alternate in numerous zones. These abnormal changes are characteristic for the borders of sedimentary petrological provinces.

No difference is found by investigating an association as a whole or by examining the heavy or light fraction apart. The

laws of the chance variations, the normal and abnormal changes, are the same. However, the number of mineral specimens in the heavy fraction is normally much greater than that in the light fraction and so the investigation of the heavy fraction gives better results for comparative purposes; also, the technique for mass-analysis of the heavy minerals is easier and more reliable.

Results of the Heavy Mineral Investigation

The stratigraphical division of the sediments of the Sunda Shelf is based on a supposed age of the sedimentary deposits and, arranged approximately from younger to older, is as follows:

(1) Krakatau group, with Y- and Z-province
(2) Deli group
(3) Bawean group
(4) Java group
  type I
  type II
(5) Borneo group
  type I—S. Borneo-type
  type II—W. Borneo-type
(6) Meratus-P. Laut group
(7) Mixed province between Borneo group type I and Meratus-P. Laut group
(8) South China Sea group
(9) Malacca group
(10) Banka-Billiton group

For the areal distribution of these provinces see pl. 1, and for the complete mineral analysis see appendix.

(*1*) *Krakatau group.*—The sediments in the Bay of Batavia and in the region of the Thousand Islands, probably stratigraphically of small thickness, are provisionally inserted in the Krakatau group. The characteristic mineral association of these deposits is hornblende-augite-hypersthene (appendix), in which hypersthene predominates.

Type samples of this group are samples nos. 7396 and 7398 with the mineralogical composition shown in table 1.

The volcanic material of which this group mainly consists is undoubtedly recent, as most of the hornblendes, augites, hypersthenes and the many opaques also present in the examined slides, still possess a glass covering. It is supposed that the volcano Krakatau has supplied the material for this province.

The sediments of the group, however, also contain hypersthenes and augites, which have been attacked strongly by weathering agencies resulting in the typical "zigzag structure" of the basal pinacoids. It is not known if the upper tuffaceous series of the Tertiary in Bantam is still noticeable north of Batavia.

From the mineral association of the samples nos. 7395, 7640, 7918, and 7239 (table 2), it appears that they do not consist purely of the Krakatau material. They are mixed with material belonging to the *Y*- and *Z*-province (to be discussed), as is deduced from the presence of epidote. Samples which are only slightly contaminated are still grouped in the Krakatau province.

Three samples in the region of this province with exceptional associations are placed, however, in other groups. Two of these samples mixed with little young Krakatau material, nos. 7393 and 7389 (table 3) are classed in a *Y*-province.

Of great importance is the mineral association of sample no. 68388 (table 3) from the Bay of Batavia. The mineralogical composition with 42 per cent garnet leads to the separation of a *Z*-province, although this sample is not pure. The hornblendes in sample no. 68388 belong to a hastingsite variety with the following optical properties: $Z \wedge c = 26°$, X = light brown, Y = light green, Z = bluish green. The augites and hypersthenes are young effusive idiomorphic pyroxines; some of these, and some of the opaques, are enveloped with volcanic glass. All other components, however, are strongly rounded and appear to be derived from old beach sand material.

In the Krakatau group are located the Thousand Islands. Umbgrove (1928,

TABLE 1.—*Standard composition of the Krakatau group*

Sample	Opaque	Transparent minerals in mutual percentages																			Location
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
7396	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	23	—	75	—	—	—	5°58′ S.L. ×106°27′ E.L.
7398	69	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	13	18	—	64	—	—	—	5°55′ S.L. ×106°39′ E.L.

TABLE 2.—*Mixed-associations in the Krakatau group*

Sample	Opaque	Transparent minerals in mutual percentages																			Location
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
7395	48	1	10	—	—	—	—	—	—	—	—	—	—	2	—	—	—	12	33	—	42	—	—	—	5°58′ S.L. ×106°12′ E.L.
7640	60	1	3	1	—	—	—	—	—	—	—	—	—	2	—	—	—	7	31	—	55	—	—	—	5°44′ S.L. ×107°15′ E.L.
7918	54	—	6	—	1	4	—	—	—	1	—	—	—	3	—	—	—	4	28	—	53	—	—	—	5°33′ S.L. ×107°31′ E.L.
7239	29	2	11	—	1	—	—	—	—	—	1	—	—	1	—	—	—	6	38	—	40	—	—	—	5°20′ S.L. ×107°25′ E.L.

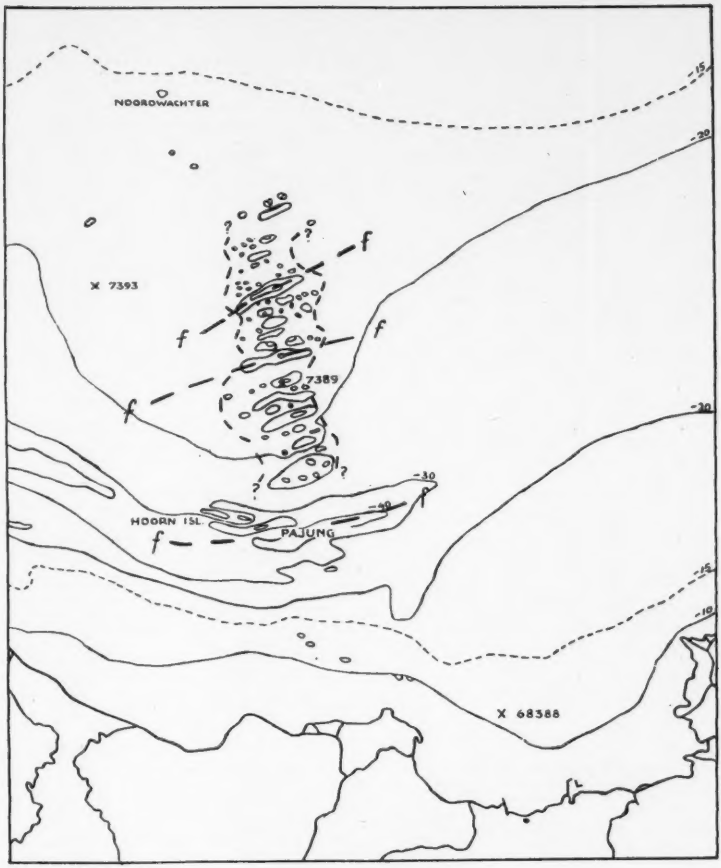
TABLE 3.—*Mineralogical composition of the Y- and Z-provinces*

Sample	Opaque	Transparent minerals in mutual percentages																			Location
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
7393	43	2	5	—	—	—	—	—	—	—	—	—	—	11	—	—	—	12	19	—	51	—	—	—	5°33′ S.L. ×106°25′ E.L.
7389	46	6	5	—	—	—	—	—	—	—	—	—	—	14	—	—	—	6	21	—	48	—	—	—	5°39½′ S.L. ×106°39′ E.L.
68388	18	4	8	42	4	1	—	—	2	—	1	—	—	20	—	—	—	3	8	—	7	—	—	—	6°3′ S.L. ×106°55′ E.L.

TABLE 4.—*Standard composition of the Deli group*

Sample	Opaque	Transparent minerals in mutual percentages																			Location
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
7371	2	—	11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	80	—	—	9	—	—	—	3°58′ N.S. ×98°52′ E.L.
7370	1	1	6	1	—	—	—	—	—	—	—	—	—	—	—	—	—	92	—	—	—	—	—	—	3°57′ N.S. ×99°11′ E.L.

1929) has investigated the coral reefs in the Bay of Batavia and those of the Thousand Islands, and expresses the opinion that the latter may be developed on a ridge-shaped elevation of the bottom originally occurring in the Pleistocene. That ridge, perhaps, could be compared with an anticline. Concordant to this



Scale 1 : 800.000.
Depths in fathoms of 1.8 m.
x7393 Sample nr 7393
f——*f* Fault (?)
– – ? – Boundary highest part supposed anticline

FIG. 3.

probability the rocks of the anticline-shaped folding would belong to a *Y*- and *Z*-province.

This opinion would lead to the view that the depths between the groups of islands are to be considered as faults converging towards Sunda Straits, and subsequently changed into erosion chan-

nels. Figure 3 shows the assumed faults and the boundary lines of the highest part of the supposed anticline.

(*2*) *Deli group.*—In contrast to its occurrence in the Krakatau group, hornblende plays the prominent part in the Deli association with percentages of 80–92. Also in this group hornblende was found covered with glass. The mineral association of the Deli group sediments is shown in table 4. Probably the tuffaceous sediments of the Deli group, like those of the pure Krakatau group, are of Recent age.

(*3*) *Bawean group.*—The samples of this group are characterized by augite in quantities of 79–98 per cent. Table 5 gives a comparison between the mineral associations of type samples belonging to the Krakatau, Deli, and Bawean groups.

After 't Hoen (1929, p. 27), post Neogene or at the utmost young Neogene leucite- and nepheline-bearing eruptive rocks occur on the island of Bawean. The augites of this group are typical for the alkaline suite of the island.

The andalusites, occurring in quantities of 14 per cent in sample no. 8320 (5 · 32′ S.L. × 112 · 52′ E.L., see appendix no. 1), are derived either from the island of Bawean or from Borneo. Due to lack of sufficient data, the distributive province of these andalusites cannot be localized with certainty. The sample is, therefore, provisionally placed within the boundary line of the Bawean group (pl. 1).

(*4*) *Java group.*—Mohr (1919) stated that the broad area, at present occupied by the sediments of the Java group, consists of very fine-graded material. He found in this area clay, loam, and sandy loam. The question arises whether all sediments of this group are recent deposits of which the detrital material is supplied from the south.

'T Hoen (1929) has described the Pleistocene and Holocene of north Java. The following material is taken from his study:

All fluviatile, lacustrine or mixed fluviatile-marine deposits, not having undergone a folding are called Quaternary. A sharp division between Holocene and Pleistocene deposits can not be drawn.

Where no volcanoes are in the neighborhood, as in the northern part of Java, bordering on the coastal alluvium, a belt of horizontally bedded Quaternary consisting of sand, clay, and stones, borders on the Tertiary hills.

The lowland plains between the marl- and limestone hills in the Rembang district are generally covered with gray-black clay.

Towards the coast the rivers transport the clay particles into the sea, where the clay flocculates forming a heavy plastic mass (including the finest particles of quartz and lime). Such areas rich in clay occupy the low coastal plain consisting of marine alluvium.

The Quaternary plains on the north coast, between Cheribon and Semarang, consist partly of volcanic grit, partly of detritus of Neogene clays and marls.

As contrasted with the Holocene swampy coastal region of northwest Java with its outgrowth of deltas far out in the sea, the coastal alluvium of central- and eastern Java does not extend that far seawards.

The enormous outgrowth of new land on the north coast is of recent age, as appears from the coastline of former and present maps. A striking example of outgrowth of a young delta shows the Tjimanuk and its branch, the Trirambatan, near Indramaju; the outgrowth of new land amounts to 4 km in 37 years. The coast of Semarang shows a less conspicuous but still considerable outgrowth of land; according to an old map of the harbor in 1847, it appears that the outgrowth of new land parallel to the coast has amounted to not less than 12 m a year, that is about 1 km in a period of 80 years.

The outlet of the channel of the Solo River, through which the muddy water of this river flows, also shows a considerable growth of land. On old maps (for instance those used by Verbeek for his field mapping at the end of the last century) the village of Sidaju is situated on the sea coast. At present this village lies 5 km inland. The channel itself seems to be deepened in the deltaic deposits over a length of 12 km.

In north Rembang, on the coastal district

TABLE 5.—*Synopsis of the Krakatau, Deli and Bawean associations*

Sample	Transparent minerals in mutual percentages																								Location
	Opaque	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
Krakatau—group																									
7396	1	–	–		–	–	–	–	–	–	–	–	–	–	–	–	–	2	23	–	75	–	–	–	5°58′ S.L. ×106°27′ E.L.
7398	69	–	5		–	–	–	–	–	–	–	–	–	–	–	–	–	13	18	–	64	–	–	–	5°55′ S.L. ×106°39′ E.L.
Deli—group																									
7371	2	–	11		–	–	–	–	–	–	–	–	–	–	–	–	–	80	–	–	9	–	–	–	3°58′ N.L. × 98°52′ E.L.
Bawean—group																									
8322	7	–	1		–	–	–	–	–	–	1	–	–	–	–	–	–	3	94	–	1	–	–	–	5°55′ S.L. ×112°55′ E.L.

near Tuban, where the Neogene limestone slopes approach the shore and not far inland the core of the Neogene anticline, rich in quartz sand, is worn down by small rivers, the shore alluvium consists chiefly of white quartz sand. Forming of some dunes is also found there. Quartz dunes are found also on the northern coast of Madura. These dunes have been formed by the N. trades, which prevail here frequently.

From the aforequoted description the conclusion can be drawn that only in a narrow region along the north coast recent sediments can be expected. Young deposits with extensive outgrowth of new land (5–6 km) are found only in front of the mouths of the large rivers of Java.

As was mentioned already under "Geological History—," vast areas in northern Java are occupied by young Tertiary tuffaceous sediments. The volcanic material was derived from the south. In connection with this and with reference to 't Hoen's considerations, three questions are of direct importance:

(a) up to which distance north of the present shoreline did the young Tertiary tuffaceous sediments extend in the young Neogene,

(b) in which part of the Java group region are still found anticlines, formed in the Pliocene-Pleistocene and where do the northern boundary lines of the Tertiary idiogeosyncline of north Java run,

(c) where in the Java group are deposited the Pleistocene detrital products of these anticlines?

As long as these questions cannot be answered, it is not permissible to infer that the investigated sediments, even if they possess the same mineral association, are stratigraphically of the same age and thus belong to the same sedimentary petrological province.

In the sedimentary rocks of the Java group, as in the sediments of the Krakatau group, are found augites, hypersthenes, and hornblends without a glass covering, having an older habit than the young idiomorphic minerals deposited after recent eruptions.

As to the detailed subdivision of the Java group association, the division into types is, for the present, preferred to the more definite denomination of a sedimentary petrological province. The age of the sediments and, also, possible mixtures of similar associations of different ages are necessarily left out of consideration.

Type I: The investigated samples consist chiefly of hornblende, augite, and hypersthene. The amounts of these minerals represented in mutual percentages varies, but augite is less abundant in this type than in the sedimentary rocks belonging to the Java group type II.

Table 6 gives a synopsis of the mineralogical composition of some type samples

TABLE 6.—*Mineralogical composition of some samples from the Java group type I*

Sample	Opaque	Transparent minerals in mutual percentages																				Location
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
7642	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	71	14	—	15	—	—	—	6°0′ S.L. ×107°58½′ E.L.
7920	7	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	46	33	—	20	—	—	—	6°0′ S.L. ×108° E.L.
4687	40	2	18	—	2	—	—	—	—	—	—	—	—	—	—	—	—	32	14	—	32	—	—	—	5°59′ S.L. ×109°15′ E.L.
4700	22	—	4	—	1	—	—	—	—	—	1	—	—	—	—	—	—	35	24	—	35	—	—	—	6°18′ S.L. ×111°44′ E.L.
4694	21	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	29	26	—	39	—	—	—	6°29′ S.L. ×113°6′ E.L.
7283	5	1	1	—	1	—	—	—	—	—	3	—	—	1	—	—	—	33	38	—	22	—	—	—	6°25′ S.L. ×114°2′ E.L.

TABLE 7.—*Samples of deviating mineralogical composition in the Java group type I*

Sample	Opaque	Transparent minerals in mutual percentages																				Location
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
7246	55	10	34	1	5	1	—	—	—	—	3	—	—	—	—	—	1	18	6	—	21	—	—	—	5°52′ S.L. ×108°40′ E.L.
7247	75	9	53	1	6	—	—	—	—	—	—	—	—	—	—	—	—	8	6	—	16	—	—	—	6°12′ S.L. ×108°49′ E.L.
7659	24	—	2	3	—	—	—	—	—	—	—	—	—	34	—	—	—	22	29	—	10	—	—	—	6°34′ S.L. ×108°51½′ E.L.
7645	61	—	37	—	9	15	—	—	—	—	—	—	—	2	—	—	—	15	11	—	11	—	—	—	6°0′ S.L. ×110°0′ E.L.
7261	82	9	36	—	1	—	—	—	3	—	9	—	—	1	—	—	—	3	22	—	16	—	—	—	5°48′ S.L. ×110°50′ E.L.
4695	65	3	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15	6	—	18	—	—	—	6°32′ S.L. ×112°20′ E.L.

TABLE 8.—*Mineralogical composition of some samples of the Java group type II*

Sample	Opaque	Transparent minerals in mutual percentages																				Location
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
7921	50	1	23	2	1	7	—	—	—	—	—	—	—	—	—	—	—	3	52	—	12	—	—	—	6°15′ S.L. ×108°30′ E.L.
7922	73	2	3	1	—	—	—	—	—	—	—	1	—	—	—	—	—	10	61	—	23	—	—	—	6°42′ S.L. ×108°39′ E.L.
7923	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	88	—	10	—	—	—	6°37′ S.L. ×109°35′ E.L.
7262	18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	49	49	—	1	—	—	—	6°8′ S.L. ×110°52′ E.L.
7263	36	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30	61	—	6	—	—	—	5°53′ S.L. ×111°19′ E.L.
7648	21	—	5	—	—	—	—	1	—	—	—	—	—	1	—	—	—	20	68	—	5	—	—	—	6°20′ S.L. ×111°16′ E.L.
7926	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	90	—	5	—	—	—	6°34′ S.L. ×111°11′ E.L.

derived from the Java group type I.

In this region occupied by this type, a number of samples occur showing the obvious feature of mixing. They differ in composition, for example, by the abundance of zircon, and in one case a percentage of epidote of 34 per cent was stated (no. 7659, table 7). Tourmaline, rutile and anatase, staurolite and andalusite, also occur sometimes in conspicuous quantities.

The above-mentioned samples have a still unknown stratigraphic position. It is not improbable, however, that the occurrence of the epidotes in sample no. 7659 is analogous to the occurrence of

TABLE 9.—*Mineralogical composition of some samples of the Borneo group type I and type II*

Sample	Transparent minerals in mutual percentages																									Location
	Opaque	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz		
Type I																										
8325	57	4	16	—	2	—	—	—	9	—	69	—	—	1	—	—	—	1	—	—	—	—	—	—		4°57′ S.L. ×113°2′ E.L.
8328	68	7	4	—	4	—	—	—	3	—	78	—	—	3	—	—	—	1	—	—	—	—	—	—		4°10′ S.L. ×113°10′ E.L.
Type II																										
7719	55	9	24	—	6	7	—	—	—	—	35	—	—	9	—	—	—	4	2	—	4	—	—	—		1°44′ S.L. ×108°8′ E.L.
7317	45	16	16	—	7	9	—	—	3	—	33	1	—	10	—	—	—	5	—	—	—	—	—	—		1°34′ S.L. ×108°19′ E.L.

the epidote in the Krakatau group leading to the separation of the *Y*-province. The six scattered samples allow no further discussion.

Type II: Of the three minerals, hornblende, augite, and hypersthene, characterizing the samples of type II (table 8), augite always occurs in the largest quantities; namely 49–90 per cent.

The mineralogical composition and areal distribution of the sediments belonging to type II (pl. 1), suggest the possibility that the Gunung Muria has furnished the greater part of the augites of this association, especially since the habit of these pyroxenes closely resembles the similar components of the tephrites and basanites from which the volcano mentioned is mainly built up (van Baren, 1948).

(*5*) *Borneo group.*—Characteristic of the deposits of this group is the occurrence of the contact metamorphic mineral andalusite in large quantities.

The original distributive provinces are situated in central, western, and southwestern Borneo. It is very probable that the sedimentation of the deposits rich in andalusite on the peneplaned old Sunda continent occurred in the Pleistocene.

Recent sandy deposits are found only in the neighborhood of the shore, because since the rise of sealevel at the end of the Pleistocene, the detrital products of Borneo have not been transported far from the coast, as has been proved by comparing the association of recent coastal materials with those of the sandy covering of this part of the bottom of the Java Sea.

In this group a type I (south Borneo) and a type II (west Borneo) are distinguished (pl. 1). The principal reason for this distinction is the different percentages of epidote.

The sediments of type I have been deposited on the denudated Banka-Billiton part of the old Sunda continent, whereas the sedimentary rocks of type II have been deposited on the northern part of the old Sunda continent consisting of the Malacca and South China Sea groups.

The Malacca and South China Sea provinces, being rich in epidote, find their continuation in western and central Borneo. The detritus of the investigated sediments of the Borneo group type II is, in general, richer in epidote than that of type I, since the influence of the distributive provinces of these epidotes (Malacca and South China Sea groups) situated in western and central Borneo, is not so perceptible as in the last mentioned type. Table 9 gives a comparison between the mineral associations of samples belonging to the different types.

(*6*) *Meratus-P. Laut group.*—In contrast with the Borneo group, in which the anti-stress mineral andalusite is the most important constituent, the minerals epidote, glaucophane, zircon, and rutile are the essential components in the sediments of the Meratus-P. Laut group.

TABLE 10.—*Mineralogical composition of some samples of the Meratus-P. Laut group*

Sample	Opaque	Transparent minerals in mutual percentages																						Location
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
7297	76	22	57	—	7	1	—	—	4	—	6	—	—	—	—	—	—	1	—	—	1	—	1	—	4°20′ S.L. ×114°51′ E.L.
7298	71	8	59	—	12	1	—	—	5	1	7	1	—	2	—	—	—	1	—	—	—	—	3	—	4°31′ S.L. ×115°10′ E.L.
7299	70	14	39	—	9	4	—	—	3	—	7	—	—	4	—	—	5	5	1	1	—	—	8	—	4°41′ S.L. ×115°26′ E.L.
7302	66	3	46	—	17	4	—	—	1	—	3	—	—	10	—	—	2	1	2	—	—	11	—	—	4°36′ S.L. ×116°17′ E.L.
8338	75	10	61	—	13	—	—	—	—	—	3	—	—	9	—	—	3	—	1	—	—	—	—	—	4°51′ S.L. ×116°17′ E.L.
7288	60	4	19	—	8	10	—	—	4	—	11	—	—	20	—	—	3	1	12	—	3	—	5	—	5°32′ S.L. ×114°33′ E.L.
7301	84	5	10	—	2	—	—	—	—	—	—	—	—	40	30	—	—	1	1	—	2	—	9	—	4°21′ S.L. ×116°17′ E.L.
8336	61	5	21	—	2	—	—	—	2	—	—	—	—	63	—	—	—	—	7	—	—	—	—	—	4°47′ S.L. ×115°51′ E.L.
7300	60	3	16	2	2	—	—	—	—	—	2	—	—	55	—	—	—	1	8	—	2	—	9	—	4°50′ S.L. ×115°42′ E.L.

TABLE 11.—*Mineralogical composition of some samples from the mixed province Borneo I-Meratus-P. Laut group*

Sample	Opaque	Transparent minerals in mutual percentages																						Location
		Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
8321	63	10	29	1	1	—	—	—	7	—	29	—	—	15	—	—	—	—	7	—	—	—	1	—	5°45′ S.L. ×112°44′ E.L.
8323	38	3	3	3	—	—	—	—	5	1	11	—	—	20	—	—	—	51	3	—	—	—	—	—	5°33′ S.L. ×112°54′ E.L.
8324	59	2	9	—	—	—	—	—	3	—	61	—	—	23	—	—	—	1	—	—	—	—	—	1	5°25′ S.L. ×112°56′ E.L.
7280	64	13	26	—	7	—	—	—	18	—	22	—	1	8	—	—	6	—	—	2	—	—	—	—	5°38′ S.L. ×113°21′ E.L.
8332	78	3	49	—	6	—	—	—	20	—	14	—	1	3	—	—	2	—	1	—	1	—	—	—	4°55′ S.L. ×114°11′ E.L.
7290	73	7	20	1	11	2	—	—	24	—	24	—	—	2	—	—	2	2	4	—	1	—	—	—	4°54′ S.L. ×114°43′ E.L.

Especially the occurrence of epidote, together with glaucophane, indicates the presence of detrital material derived from dynamic metamorphic rocks as encountered in the Bobaris-Meratus Mountains.

The picotites, also occurring in the investigated samples, are derived from the peridotites and serpentines from this region.

For the present, the samples characterized by these minerals are taken together within the bounds of one province.

It is known that the Bobaris-Meratus Mountains, containing pre-Tertiary rocks, were uplifted by early Tertiary orogenesis. It is to be expected that young Pliocene sediments in the eastern part of the Barito Basin, like the Quaternary deposits, mainly consist of clastic material of which the Meratus Mountains are the original distributive province.

From the areal distribution of the Borneo group type I (pl. 1), it appears that sediments rich in andalusite can be expected in the western part of the Barito region.

(7) *Mixed province between the Borneo group type I and the Meratus-P. Laut Group.*—In the region of this province mixing between material of the Borneo group type I and material of the Meratus-P. Laut group took place in the Pleistocene. The sediments consequently contain the mineral associations of both groups.

It is notable that staurolite occurs in larger quantities than in the examined samples of the pure Borneo group type I. On the one hand, it is possible that the sediments of the eastern part of the Bor-

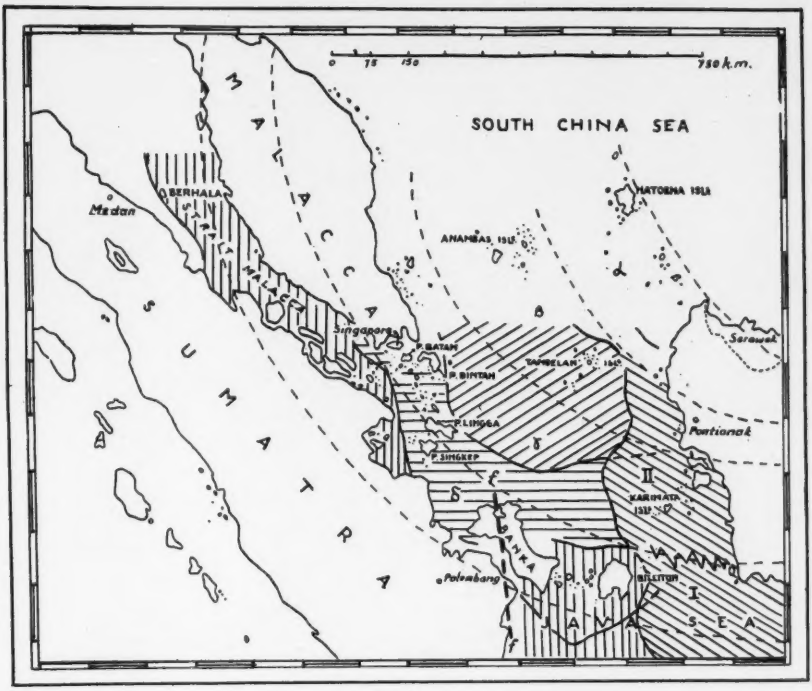


Fig. 4

α, β, γ, δ. Distribution of the zones after { VAN BEMMELEN and ZEIJLMANS v. EMMICHOVEN

f – – – f Fault (after Hövig)

Boundary of the provinces

Boundary of the subdivision

} vide Appendix nr 1

Borneo - group { S. Borneo - type / W. Borneo - type

South China Sea | Malacca | Banka - Billiton

group

neo group type I are richer in staurolite than the few samples belonging to this area which have been examined. On the other hand, it must be recognized that material of still unknown origin may also have played a part during the formation of the sediment. Only a detailed investigation will carry us nearer to the solution of this problem.

Table 11 is a schematic outline of the

TABLE 12.—*Mineralogical composition of samples of the South China Sea group and their differentiation in zones*

Sample	Transparent minerals in mutual percentages																									Location
	Opaque	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz		
7357	50	12	46	—	3	1	—	—	—	—	15	—	—	7	—	—	—	15	—	—	1	—	—	—		1°24′ N.L. ×104°58′ E.L.
7332	63	13	59	—	2	—	1	—	2	—	3	—	—	9	—	—	—	3	—	—	6	—	—	—		0° 2′ N.L. ×105°10′ E.L.
7333	61	13	31	—	—	—	—	—	4	—	5	—	—	10	2	—	—	18	1	—	15	—	—	—		0°12′ N.L. ×105°27′ E.L.
7703	75	12	27	4	3	2	—	1	—	—	3	—	—	30	—	—	—	13	—	—	5	—	—	—		0°15′ S.L. ×105°28′ E.L.
7331	61	14	43	—	1	1	—	—	1	—	7	—	—	20	—	—	—	9	—	—	3	—	—	—		0°12′ S.L. ×105°39′ E.L.
7707	52	16	12	5	2	7	—	—	1	—	4	—	—	33	—	—	—	17	—	—	3	—	—	—		0°13′ S.L. ×105°41′ E.L.
7708	56	15	14	2	2	4	—	1	—	—	4	—	—	40	—	—	—	15	—	—	3	—	—	—		0° 3′ S.L. ×105°55′ E.L.
7700	80	11	33	1	7	10	—	—	—	—	1	—	—	23	3	—	—	6	1	—	4	—	—	—		0°48′ S.L. ×106°17′ E.L.
7699	71	8	25	1	5	14	—	—	—	—	1	—	—	15	—	—	—	22	—	—	9	—	—	—		0°47′ S.L. ×106°35′ E.L.
7728	60	5	14	3	2	5	—	1	—	—	7	—	—	19	3	—	—	27	1	—	13	—	—	—		0°47′ N.L. ×105°26′ E.L.
7334	55	9	12	1	2	—	—	—	1	—	8	—	—	22	7	—	—	28	—	—	10	—	—	—		0°22′ N.L. ×105°45′ E.L.
7329	73	16	38	—	1	1	—	—	3	—	7	—	—	18	—	—	—	10	—	—	6	—	—	—		0° 1′ S.L. ×106°14′ E.L.
7727	62	17	35	2	2	5	—	—	1	1	6	—	—	11	—	—	—	16	—	—	3	—	1	—		1° 0′ N.L. ×105°39′ E.L.
7335	76	17	59	—	2	—	—	—	—	—	2	—	—	10	1	—	—	6	—	—	3	—	—	—		0°35′ N.L. ×106° 1′ E.L.
7726	85	20	22	1	4	6	—	—	—	—	4	—	—	25	—	—	—	9	1	—	5	—	3	—		1°58′ S.L. ×105°59′ E.L.
7725	85	18	31	1	7	2	—	—	1	—	9	—	—	17	—	—	—	11	—	—	1	—	2	—		1°53′ S.L. ×106°16′ E.L.
7336	62	11	27	5	3	—	—	—	—	—	5	—	—	18	4	—	—	24	1	—	2	—	—	—		0°47′ N.L. ×106°17′ E.L.
7337	55	8	46	—	1	—	—	—	1	—	5	—	—	9	2	—	—	26	—	—	2	—	—	—		0°50′ N.L. ×106°39′ E.L.
7353	85	17	22	1	3	—	—	—	—	—	7	—	—	32	—	—	—	16	—	—	2	—	—	—		1°30′ N.L. ×106°15′ E.L.
7724	76	17	25	1	3	7	—	—	—	—	1	—	—	28	—	—	—	11	—	—	1	—	—	—		1°50′ N.L. ×106°32′ E.L.
7352	70	3	64	—	—	1	—	—	—	—	8	—	—	9	—	—	—	9	1	—	5	—	—	—		1°37′ N.L. ×106°36′ E.L.

TABLE 13.—*Mineralogical composition of some samples of the South China Sea and Malacca groups*

Sample	Transparent minerals in mutual percentages																									Location
	Opaque	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz		
South China Sea—group																										
7351	77	9	29	1	1	1	—	—	1	—	8	—	—	29	—	—	—	19	1	—	1	—	—	—		1°38′ N.L. ×106°56′ E.L.
7324	54	1	29	1	6	4	—	1	3	—	13	—	—	28	—	—	—	10	—	1	2	—	1	—		0°19′ S.L. ×108° E.L.
Malacca—group																										
7360	44	7	22	—	—	—	—	—	—	—	5	—	—	16	2	—	—	15	1	—	33	—	—	—		1°15′ N.L. ×103°24′ E.L.
7358	39	4	10	1	2	—	—	—	1	—	7	—	—	11	3	—	—	19	7	—	35	—	—	—		1°30′ N.L. ×104°36′ E.L.
7701	46	2	3	3	1	1	—	—	—	—	1	—	—	30	—	—	—	21	2	—	36	—	—	—		1°14½′ N.L. ×105°55½′ E.L.
7381	57	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	15	—	77	—	—	—		1°43′ S.L. ×105°11′ E.L.

mineralogical composition of some samples, showing the chaotic character of a province resulting from the mixing of detrital material transported from two different directions.

(*8*) *South China Sea group.*—The samples of the South China Sea group and of the Malacca group mineralogically show a great resemblance, There are, however, enough characteristic differences on which to base the separation into two different provinces.

Characteristic of the South China Sea group is the occurrence of epidote and hornblende, which are fairly coarse-grained. The hornblende of the South

TABLE 14.—*Mineralogical composition of some samples of the Banka-Billiton group*

Sample	Transparent minerals in mutual percentages																								Location
	Opaque	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz	
Banka-Billiton—group																									
7368 c.g.	60	63	24	—	—	—	—	—	—	—	4	—	—	2	—	—	—	3	1	—	1	—	—	2	3°56′ N.L. ×100°11′ E.L.
7312 c.g.	65	31	52	—	2	9	—	—	—	—	3	—	—	1	—	—	—	2	—	—	—	—	—	—	2°32′ S.L. ×106°58′ E.L.
7224 f.g.	83	2	75	—	5	1	—	—	3	—	8	—	—	2	—	—	—	3	—	1	—	—	—	—	3°40′ S.L. ×106°20′ E.L.
7243 f.g.	48	6	72	1	9	1	—	—	—	—	1	—	—	1	—	—	—	1	3	—	5	—	—	—	4°49′ S.L. ×108°11′ E.L.
Northern zone in Str. Malacca																									
7363 c.g.	56	40	37	—	1	5	—	—	—	—	—	—	—	6	—	—	—	11	—	—	—	—	—	—	1°50′ N.L. ×102°30′ E.L.
Berhala—group																									
7739 c.g.	25	18	8	—	—	—	—	—	—	—	—	—	—	6	—	—	—	49	—	—	7	—	—	—	3°23′ N.L. ×100° E.L.

c.g. =coarse grained
f.g. =fine grained

China Sea group is mostly blue-green and of a lighter shade compared with the dark brown-green variety of the Malacca group, possessing the habit of the effusive hornblende.

In the South China Sea region varieties in the mineral associations of the sediments are striking. Though these varieties do not allow a separation into types they are, nevertheless, a reason for a certain amount of detailing.

The differentiations based on such a detailed analysis lead to the distinguishing of boundaries of zones varying in the mutual percentages of the minerals found.

It is considered to be probable that the zones found are outcrops of groups of rocks which form the bottom of the South China Sea.

The South China Sea group is the β-zone of the Kristallinicum on the continent of Borneo (see p. 89).

(*9*) *Malacca group.*—The difference in mineralogical composition between this group and the South China Sea group depends chiefly on the occurrence of hypersthene in larger quantities.

The Malacca group, to which the Pahang volcanic series (Permocarboniferous or Triassic volcanism) of Scrivenor (1931) belongs (see fig. 4), is equivalent to the γ-zone of the Kristallinicum on the continent of Malacca and in western Borneo.

The central part of this province, in which the Riouw and Lingga Archipelagoes and the part of the old Sunda continent north of Banka and Billiton are situated, are unfortunately insufficiently sampled (pl. 1).

A further detailing is therefore not possible, though the occurrence, for instance, of tourmaline-zircon-rutile zones probably must be expected since granites are exposed on several islands in this region.

A comparison between the mineral associations of some type samples belonging to the South China Sea group and Malacca group is shown in table 13.

(*10*) *Banka-Billiton group.*—The Banka-Billiton group is characterized by the mineral association of tourmaline-zircon-rutile.

In the Straits of Malacca are found two narrow zones, also belonging to this "acid" group (see pl. 1). One of these

TABLE 15.—*Standard composition of the sedimentary petrological provinces of the Sunda Sea*

Group	Standard Composition																					
		Transparent minerals in mutual percentages																				
	Opaque	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Glaucophane	Amphibole	Augite	Hypersthene	Topaz	Picotite
Krakatau group	31	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	24	31	44	–	–
y—Province	46	6	5	–	–	–	–	–	–	–	–	–	–	14	–	–	6	21	48	–	–
z—Province	18	4	8	42	4	1	–	–	2	–	1	–	–	20	–	–	3	8	7	–	–
Deli group	1	1	6	1	–	–	–	–	–	–	–	–	–	–	–	–	92	–	–	–	–
Bawean group	2	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	98	1	–	–
Java group																					
type I	30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	33	42	25	–	–
type II	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	90	5	–	–
Borneo group																					
type I	68	7	4	–	4	–	–	–	3	–	78	–	–	3	–	–	1	–	–	–	–
type II	76	16	25	1	5	5	–	1	1	–	22	–	–	15	–	–	8	1	–	–	–
Meratus-P. Laut group	60	4	19	–	8	10	–	–	4	–	11	–	–	20	–	3	1	12	3	–	5
Mixed Province	59	2	9	–	–	–	–	–	3	–	61	–	–	23	–	–	1	–	–	1	–
S. China Sea group	77	9	29	1	1	1	–	–	1	–	8	–	–	29	–	–	19	1	1	–	–
Malacca group	44	7	22	–	–	–	–	–	–	–	5	–	–	16	2	15	15	1	33	–	–
Banka-Billiton group	74	24	64	–	4	–	–	–	1	–	1	–	–	1	–	–	3	–	2	–	–

zones is richer in hornblende than is the standard Banka-Billiton group, whereas the southern zone is not only rich in hornblende, but also contains orthite (Berhala group).

In the region of the Banka-Billiton group the grain sizes of the sediments containing tourmaline-zircon-rutile are coarser than those of the sands with the same mineral association located farther south in the strip bordering on the effusive Krakatau and Java groups. The coarse Banka-Billiton material is richer in tourmaline than the sands of this province located farther south and east, as table 14 shows.

According to the opinion of the present authors, the coarse-grained part of the Banka-Billiton group (Banka, Billiton, and Straits of Malacca) can be correlated with the δ-zone of the Kristallinicum on the continent of Malacca and western Borneo.

The continuation of the southern part of the Malacca group is broken off on Banka against the Banka-Billiton group, presumably where the fault of Hövig (1920) is supposed to be located (fig. 4).

The continuation of the δ-zone of the Kristallinicum is not found in the region of the old divide, but is in East Sumatra.

SUMMARY

The investigation of samples from the bottom of the Sunda shelf has led to the separation of ten sedimentary petrological provinces. The provinces are characterized by the mineral associations shown in table 15.

The mineralogical composition and areal distribution of the distinguished provinces led to the following consideration:

The north boundary of the Java idiogeosyncline is presumably situated in the Java Sea in the region of the Java and Krakatau group (see pl. 2; sketch sections A–B, C–D).

In the Krakatau group as in the Java group the investigated sediments contain minerals of different habit. Many hypersthene and augite grains possess the so-called "zigzag structure," resulting on the (001) planes typical after weathering along the cleavage planes. Young effusive augites and hypersthenes, still possessing a volcanic glass cover accompany these old-appearing augites and hypersthenes. Whereas the young-appearing pyroboles probably are derived from recent volcanic eruptions, the ragged specimens must undoubtedly be credited with a greater age. For the pres-

ent it is, however, not yet known how far north of the coast line the young Tertiary tuffaceous sediments of North Java (from Batavia to Madura) extend. Also, it is not known whether in the region of the Java group structures are present from which detrital products have been derived to partly fill up the synclines during the Pleistocene.

The sediments in the Bay of Batavia and in the region of the Thousand Islands are provisionally classified in the Krakatau group. Whether the tuffaceous youngest series of the Tertiary of Bantam (the equivalents of the Upper Palembang beds) are still to be observed north of Batavia, is left undecided though the occurrence of old effusive material is an indication.

In the region of this group mineral associations are further encountered which stratigraphically are older and separated as Y- and Z-provinces. These rocks presumably form the core of an assumed anticline-shaped elevation, on which the coral reefs in the Bay of Batavia and those of the Thousand Islands have been formed. Figure 3 shows the boundary lines of the highest part of this anticline and the erosion channels (faults) which accompany it.

The Deli group is characterized by hornblende, occurring in quantities of 80–92 per cent. In this group are also found hornblendes, covered with glass. Plate 2 (sketch section E–F) shows the Deli group deposited unconformably on the supposed Tertiary and Quaternary. The basement on which the Tertiary is deposited is the Berhala group.

The Bawean group is very rich in augite, which occurs in the examined samples in quantities of 79–98 per cent. There is a great resemblance mineralogically between the sediments of the Bawean group and those of the Java group type II, of which the augites are derived for the most part from the Mediterranean magma-type of the Gunung Muria.

As contrasted with the volcanic groups, in which effusive amphiboles and pyroxenes play the leading part, the minerals epidote, glaucophane, zircon, rutile, and picotite come into prominence in the sediments of the Meratus-P. Laut group. The epidotes and glaucophanes are derived from P. Laut and from the Bobaris-Meratus Mountains, being the east boundary of the Barito Basin. The source of the picotites must be the peridotites and serpentines, occurring in these regions. Young Pliocene sediments in the eastern part of the Barito Basin will have been formed by deposition of clastic material derived from the Meratus Mountains, uplifted by orogenies in the young Tertiary.

The Quaternary deposits in this part of the basin will be composed chiefly of material of which the primary distributive province is the Meratus Mountains. For the present the investigated samples are placed sediment petrographically in the same province.

The Borneo group is characterized by the anti-stress mineral andalusite, found in large quantities. The primary distributive provinces of these andalusites are situated in Central-, W.- and SW.-Borneo. In the Borneo group a type I (south Borneo-type) and a type II (west Borneo-type) are to be distinguished. Type II is richer in epidote than type I. Type I is deposited on the peneplaned Banka-Billiton part of the old Sunda continent, whereas type II was deposited on the northern part of the old continent consisting of the Malacca and South China Sea groups.

In the Pleistocene mixing took place between the Borneo group type I and the Meretus-P. Laut group, whereby a mixed province was formed.

In the western part of the Barito region sediments rich in andalusite may be expected. In this part of the basin the sediments are probably also richer in staurolite. This can be inferred from the rather high percentages of this mineral found in the mixed province separated as a group in which the mineral association of Borneo type I and Meratus-P. Laut group occur together. Though this supposition still needs confirmation, the alternative of a southern source of the material seems less probable on account of the coarse granularity of the material.

Umbgrove has given a general view of

the paleogeographic conditions in the Tertiary in the East Indian Archipelago. Based on the geological data available at that time, he presumed the existence of land in the region now occupied by the Java and South China Sea. This part of the old Sunda continent, petrologically consisting of the South China Sea, Malacca, and Banka-Billiton groups had in the Tertiary acted as distributive source.

The rocks of the area which is occupied by the Banka-Billiton province of today have supplied detrital material to the idiogeosynclinal regions of Sumatra, Java and SE. Borneo (Barito Basin), bordering on this part of the old Sunda continent. The sediments formed from material of this group (tourmaline-zircon-rutile-association), will, owing to grading, be richer in zircon and poorer in tourmaline and also finer of grain the farther they are deposited from the distributive province.

The old continent with the exception of the monadnocks probably had been peneplaned in the Mio-Pliocene. Only by an extensive investigation of the heavy mineral associations of the Tertiary sediments of the idiogeosynclines, bordering on this distributive province, can be determined when in the Tertiary and from which parts of this province supply of clastic material was stopped.

The upper reaches of the Tertiary (?) rivers of the old continent, located in the Sunda Sea, very probably reached by headward erosion the old water divide Malacca-Riouw-Lingga Archipelago-Banka-Billiton in the Pliocene. Of a Tertiary (?) North Sunda stream only a scar on the surface of the old continent should be recognizable. Plate 2 shows the isobathes, from which a supposed Pleistocene river system can be reconstructed (fig. 1). The isobathes, however, coincide with the contour lines of a peneplaned surface of the old Sunda continent which reached its final stage of peneplanation at the end of the Pleistocene. They are related to the contour lines of the surface of the Borneo group, deposited in the Pleistocene on the denudated South China Sea, Malacca and Banka-Billiton groups. Whereas clastic material was supplied from Borneo, the presumed anticlines east of Deli and north of Java were peneplaned, whereby the synclines probably have been partly filled up with detritus from those anticlines. Owing to this the bottom of the Sunda Sea acquired the appearance of a peneplain drowned at the end of the Pleistocene furnished with Pleistocene rivers, of which course and shape however were affected very probably by the primary Tertiary configuration.

From geological investigations carried out by van Bemmelen (1939) and Zieljmans van Emmichoven (1939) of the Kristallinicum of Borneo, it appears that in West Borneo this formation forms the eastern part of the continental Sunda region, whereas the western part of this old region is formed by Malacca. The authors mentioned understand by the "Kristallinicum" a "geological unit consisting of chiefly acid plutonic rocks, regional metamorphic, contact metamorphic and dynamic metamorphic rocks, which last ones are altered for the greater part by contact metamorphism." Four geotectonic zones can be distinguished, namely: zones α, β, γ, and zone δ.

The results of the sedimentary petrological investigation are the following: zone β corresponds with the "South China Sea group," zone γ with the "Malacca group" and zone δ with the "coarse-grained part of the Banka-Billiton group." From this it follows also, that the trend-lines of the zones in the northwestern part of the Sunda Sea, sketched by van Bemmelen and Zeijlmans van Emmichoven, are not covered by the boundary lines of the sedimentary petrological equivalents of the occurrences of the Kristallinicum on the mainland.

Figure 4 shows the zones or groups occurring in the central part of the old Sunda region between Malacca and West Borneo and also that the new "zone γ" on Banka contacts the new "zone α," there where the fault of Hövig is presumably located. The "zone δ" of the Kristallinicum is found back in east Sumatra, but not in the region of the old divide, where in the new "zone γ" granites also occur.

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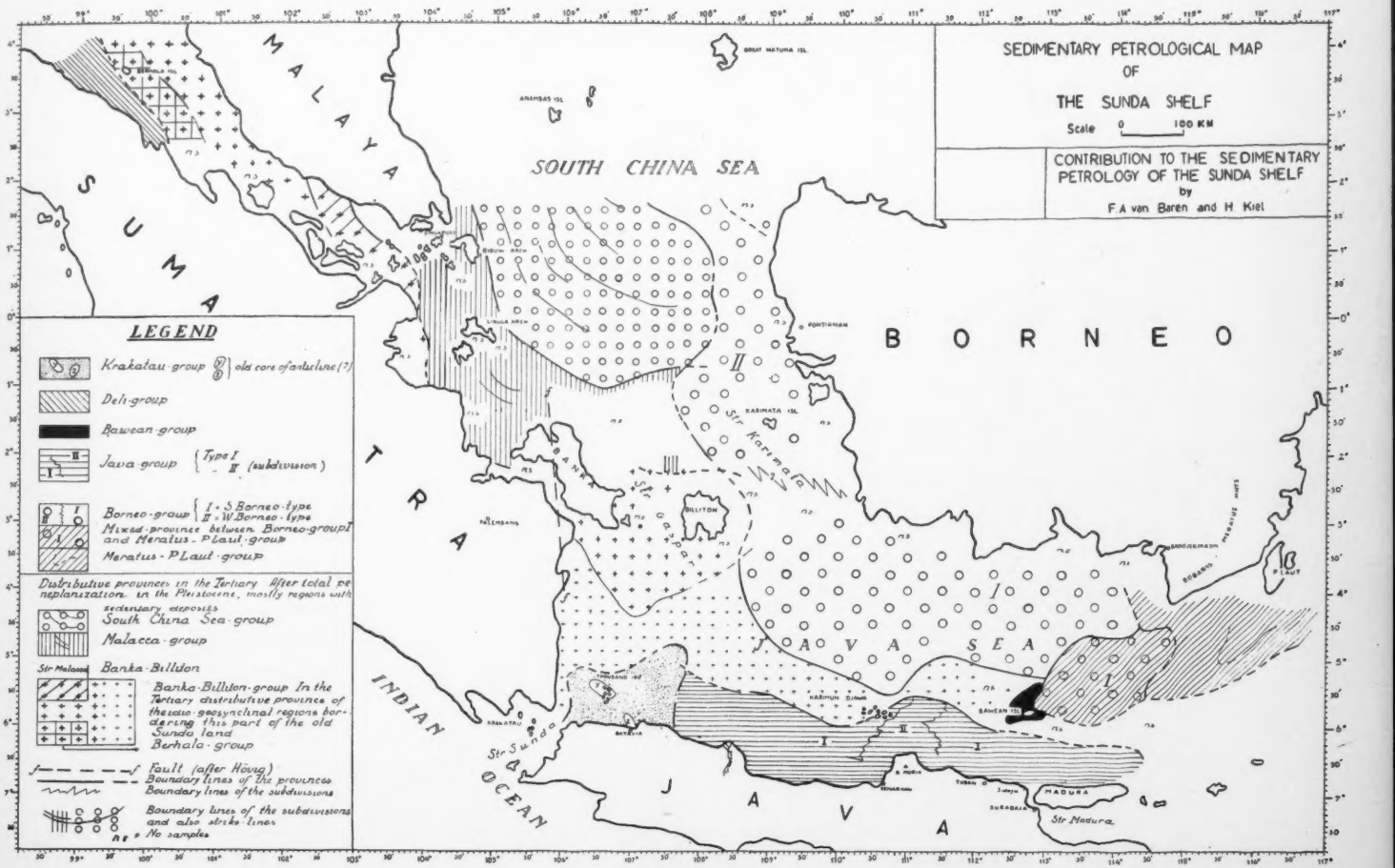
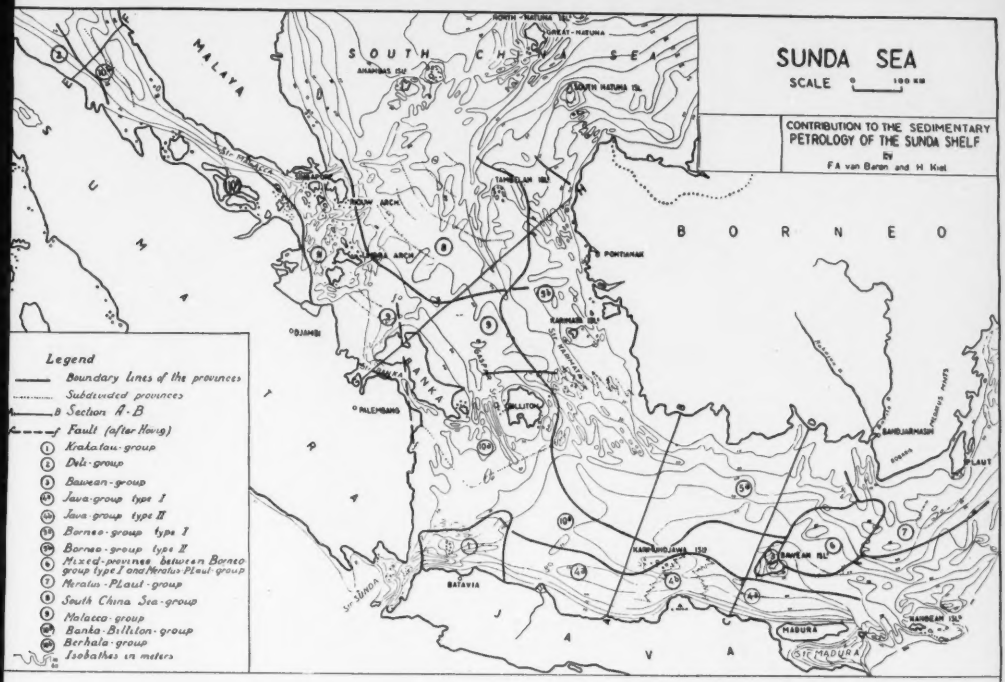

SEDIMENTARY PETROLOGICAL MAP
OF
THE SUNDA SHELF
Scale 0 100 KM
CONTRIBUTION TO THE SEDIMENTARY PETROLOGY OF THE SUNDA SHELF
by
F.A van Baren and H. Kiel
LEGEND
Krakatau-group
old core of anticline (?)
Deli-group
Bawean-group
Java-group
Type I
II (subdivision)
Borneo-group
I = S.Borneo-type
II = W.Borneo-type
Mixed-province between Borneo-group I and Meratus - P.Laut-group
Meratus - P.Laut-group
Distributive provinces in the Tertiary (after total peneplanization in the Pleistocene, mostly regions with sedentary deposits)
South China Sea-group
Malacca-group
Str Malacca
Banka-Billiton
Banka-Billiton-group In the Tertiary distributive province of the actic geosynchinal regions bordering this part of the old Sunda land
Berhala-group
Fault (after Höng)
Boundary lines of the provinces
Boundary lines of the subdivisions
Boundary lines of the subdivisions and also strike lines
No samples
SOUTH CHINA SEA
MALAYA
SUMATRA
BORNEO
JAVA SEA
INDIAN OCEAN
JAVA
Str Karimata
Str Gaspar
Str Sunda
Str Madura
BANKA
BILLITON
PALEMBANG
BATAVIA
MADURA
PONTIANAK
BANJERMASIN
BAWEAN
KRAKATAU

PLATE 1.



SCETCH SECTIONS VERTICAL SCALE 100 X HORIZONTAL

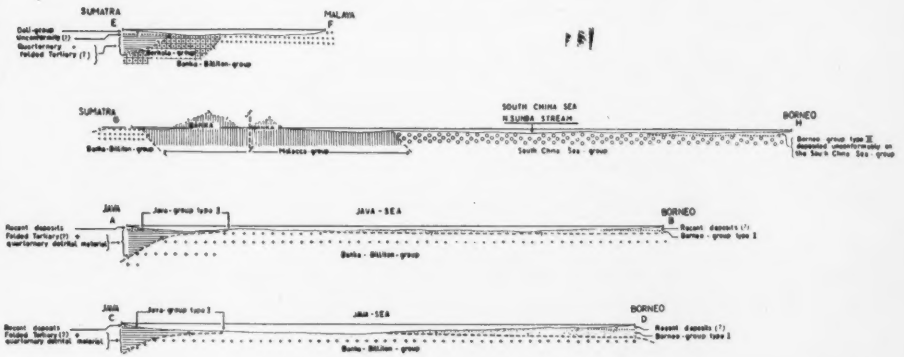


PLATE 2.

Sample	Location	Opaque	Transparent minerals in mutual percentages																									
			Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz
	KRAKATAU GROUP																								
7236	5°25′ S.L. ×106°13′ E.L.	66	—	25	—	2	—	—	—	—	—	1	—	—	—	—	—	—	4	27	—	42	—	—	—
7394	5°45½′ S.L. ×106°13′ E.L.	45	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	28	23	—	48	—	—	—
7395	5°58′ S.L. ×106°12′ E.L.	48	1	10	—	—	—	—	—	—	—	—	—	—	2	—	—	—	12	33	—	42	—	—	—
7396	5°58′ S.L. ×106°27′ E.L.	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	23	—	75	—	—	—
7391	5°50′ S.L. ×106°24′ E.L.	29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9	23	—	68	—	—	—
7392	5°43′ S.L. ×106°25′ E.L.	55	1	6	—	—	—	—	—	—	—	—	—	—	2	—	—	—	18	17	—	56	—	—	—
Y 7393	5°33′ S.L. ×106°25′ E.L.	43	2	5	—	—	—	—	—	—	—	—	—	—	11	—	—	—	12	19	—	51	—	—	—
Y 7389	5°39½′ S.L. ×106°39′ E.L.	46	6	5	—	—	—	—	—	—	—	—	—	—	14	—	—	—	6	21	—	48	—	—	—
7390	5°49′ S.L. ×106°40′ E.L.	10	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	10	23	—	66	—	—	—
7398	5°55′ S.L. ×106°39′ E.L.	69	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	13	18	—	64	—	—	—
7397	5°59′ S.L. ×106°39′ E.L.	52	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	35	—	55	—	—	—
Z 68388	6° 3′ S.L. ×106°53′ E.L.	18	4	8	42	4	1	—	—	2	—	1	—	—	20	—	—	—	3	8	—	7	—	—	—
7401	5°55′ S.L. ×106°48′ E.L.	63	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	26	—	63	—	—	—
7402	5°50′ S.L. ×106°45½′ E.L.	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	24	—	76	—	—	—
7404	5°40′ S.L. ×106°57′ E.L.	31	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	24	31	—	44	—	—	—
7405	5°50′ S.L. ×106°57′ E.L.	23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	47	—	45	—	—	—
7217	5°50′ S.L. ×107° E.L.	71	—	11	—	1	—	—	—	—	—	—	—	—	—	—	—	—	15	27	—	46	—	—	—
7238	5°37′ S.L. ×107°13′ E.L.	40	—	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	10	—	66	—	—	—
7640	5°44′ S.L. ×107°15′ E.L.	60	1	3	1	—	—	—	—	—	—	—	—	—	2	—	—	—	7	31	—	55	—	—	—
7919	5°50′ S.L. ×107°31′ E.L.	25	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	39	—	52	—	—	—
7918	5°33′ S.L. ×107°31′ E.L.	54	—	6	—	1	4	—	—	—	1	—	—	—	3	—	—	—	4	28	—	53	—	—	—
7239	5°20′ S.L. ×107°25′ E.L.	29	2	11	—	1	—	—	—	—	—	1	—	—	1	—	—	—	6	38	—	40	—	—	—
7240	5° 3′ S.L. ×107°37′ E.L.	38	8	60	1	2	1	—	—	—	—	2	—	—	3	—	—	—	—	3	—	20	—	—	—
	DELI GROUP																								
7371	3°58′ N.L. × 98°52′ E.L.	2	—	11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	80	—	—	9	—	—	—
7370	3°57′ N.L. × 99°11′ E.L.	1	1	6	1	—	—	—	—	—	—	—	—	—	—	—	—	—	92	—	—	—	—	—	—
	BAWEAN GROUP																								
8320	5°32′ S.L. ×112°52′ E.L.	42	1	3	—	2	—	—	—	1	—	14	—	—	—	—	—	—	—	79	—	—	—	—	—
8319	5°41′ S.L. ×112°39′ E.L.	2	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	98	—	1	—	—	—
7275	5°56′ S.L. ×112°31′ E.L.	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1	98	—	—	—	—	—
8322	5°55′ S.L. ×112°55′ E.L.	7	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—	3	94	—	1	—	—	—
	JAVA GROUP type I																								
7642	6° 0′ S.L. ×107°58½′ E.L.	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	71	14	—	15	—	—	—
7920	6° 0′ S.L. ×108° E.L.	7	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	46	33	—	20	—	—	—
4701	6° 7′ S.L. ×108°50′ E.L.	80	2	34	—	3	—	—	—	—	—	—	—	—	—	—	—	—	33	6	—	22	—	—	—
4687	5°59′ S.L. ×109°15′ E.L.	40	2	18	—	2	—	—	—	—	—	—	—	—	—	—	—	—	32	14	—	32	—	—	—
4698	6°14½′ S.L. ×109°43′ E.L.	80	2	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	45	28	—	20	—	—	—
4704	6°23′ S.L. ×109°53′ E.L.	27	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60	27	—	11	—	—	—
4697	6°23½′ S.L. ×110°10½′ E.L.	27	—	4	—	2	—	—	—	—	—	4	—	—	—	—	—	—	59	12	—	19	—	—	—
7646	6°30′ S.L. ×110° 7′ E.L.	35	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	28	33	—	36	—	—	—

APPENDIX—CONTRIBUTION TO THE SEDIMENTARY PETROLOGY OF THE SUNDA-SHELF—(*continued*)

Sample	Location	Opaque	Transparent minerals in mutual percentages																								
			Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz
4692	6°34′ S.L. ×111°31½′ E.L.	52	—	13	—	2	—	—	—	1	—	1	—	—	1	—	—	—	27	17	—	38	—	—	—
4696	6° 6′ S.L. ×111°26′ E.L.	56	1	12	—	1	—	—	—	1	—	3	—	—	1	—	—	1	60	11	1	7	—	—	—
7649	6° 0′ S.L. ×111°30′ E.L.	70	2	16	—	4	4	—	—	—	—	—	—	—	—	—	—	—	31	19	—	14	—	—	—
4700	6°18′ S.L. ×111°44′ E.L.	22	—	4	—	1	—	—	—	—	—	1	—	—	—	—	—	—	35	24	—	35	—	—	—
4705	6°14′ S.L. ×112°11½′ E.L.	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	27	41	—	32	—	—	—
4688	6°11′ S.L. ×112°35′ E.L.	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	32	22	—	46	—	—	—
7276	6°16′ S.L. ×112°38′ E.L.	12	—	2	—	—	—	—	—	—	—	1	—	—	—	—	—	—	38	33	—	26	—	—	—
4699	6°26′ S.L. ×112°52½′ E.L.	16	—	5	1	—	—	—	—	—	—	—	—	—	1	—	—	—	50	19	—	24	—	—	—
7277	6°42′ S.L. ×112°49′ E.L.	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	59	26	—	15	—	—	—
7278	6°23′ S.L. ×112°57′ E.L.	4	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	45	29	—	25	—	—	—
4694	6°29′ S.L. ×113° 6′ E.L.	21	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	29	26	—	39	—	—	—
7653	6°38′ S.L. ×113°11′ E.L.	11	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	47	28	—	23	—	—	—
7654	6°44′ S.L. ×113°43′ E.L.	8	—	1	1	2	—	—	—	—	—	—	—	—	2	—	—	—	27	37	—	30	—	—	—
4702	6°36½′ S.L. ×113°37½′ E.L.	50	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	45	26	—	28	—	—	—
4693	6°40′ S.L. ×113°44′ E.L.	46	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	33	36	—	31	—	—	—
7283	6°25′ S.L. ×114° 2′ E.L.	5	1	1	—	1	—	—	—	—	—	3	—	—	1	—	—	—	33	38	—	22	—	—	—
7662	6°48′ S.L. ×114°15′ E.L.	30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	33	42	—	25	—	—	—
7246	5°52′ S.L. ×108°40′ E.L.	55	10	34	1	5	1	—	—	—	—	3	—	—	—	—	—	1	18	6	—	21	—	—	—
7247	6°12′ S.L. ×108°49′ E.L.	75	9	53	1	6	—	—	—	—	—	—	—	—	1	—	—	—	8	6	—	16	—	—	—
7659	6°34′ S.L. ×108°51½′ E.L.	24	—	2	3	—	—	—	—	—	—	—	—	—	34	—	—	—	22	29	—	10	—	—	—
7645	6° 0′ S.L. ×110° 0′ E.L.	61	—	37	—	9	15	—	—	—	—	—	—	—	2	—	—	—	15	11	—	11	—	—	—
7261	5°48′ S.L. ×110°50′ E.L.	82	9	36	—	1	—	—	—	3	—	9	—	—	1	—	—	—	3	22	—	16	—	—	—
4695	6°32′ S.L. ×112°20′ E.L.	65	3	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15	6	—	18	—	—	—
	JAVA GROUP type II																								
7921	6°15′ S.L. ×108°30′ E.L.	50	—	23	2	1	7	—	—	—	—	—	—	—	—	—	—	—	3	52	—	12	—	—	—
7922	6°42′ S.L. ×108°39′ E.L.	73	2	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	10	61	—	23	—	—	—
7923	6°37′ S.L. ×109°35′ E.L.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	88	—	10	—	—	—
7262	6° 8′ S.L. ×110°52′ E.L.	18	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	49	49	—	1	—	—	—
7263	5°53′ S.L. ×111°19′ E.L.	36	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30	61	—	6	—	—	—
7648	6°20′ S.L. ×111°16′ E.L.	21	—	5	—	—	—	—	1	—	—	—	—	—	1	—	—	—	20	68	—	5	—	—	—
7926	6°34′ S.L. ×111°11′ E.L.	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	90	—	5	—	—	—
	BORNEO GROUP type I																								
8333	4°36′ S.L. ×114°18′ E.L.	58	4	35	—	6	—	—	—	6	—	46	—	—	1	—	—	—	—	—	2	—	—	—	—
7296	4°19′ S.L. ×113°30′ E.L.	60	5	47	—	6	—	—	—	8	—	31	—	—	1	—	—	—	—	—	2	—	—	—	—
8328	4°10′ S.L. ×113°10′ E.L.	68	7	4	—	4	—	—	—	3	—	78	—	—	3	—	—	—	1	—	—	—	—	—	—
8325	4°57′ S.L. ×113° 2′ E.L.	57	4	16	—	2	—	—	—	9	—	69	—	—	—	—	—	—	—	—	—	—	—	—	—
8326	5°14′ S.L. ×113° 2′ E.L.	68	9	15	—	2	—	—	—	6	—	65	—	—	—	—	—	—	—	—	—	2	—	—	—
7272	4°57′ S.L. ×112° 7′ E.L.	72	1	26	1	11	1	—	—	9	—	48	—	—	—	—	—	—	1	1	—	2	—	—	—
7271	4°40′ S.L. ×111°58′ E.L.	75	6	43	—	12	—	—	—	9	—	29	—	—	—	—	—	—	—	—	1	—	—	—	—
7270	4°21′ S.L. ×111°50′ E.L.	68	9	44	—	7	—	—	—	3	—	25	—	—	1	—	—	—	6	4	1	—	—	—	—
7269	3°46′ S.L. ×111°23′ E.L.	74	3	69	—	1	—	—	—	1	—	13	—	—	3	—	—	—	2	6	—	2	—	—	—
7267	4°28′ S.L. ×111°26′ E.L.	67	8	32	—	8	—	—	—	—	—	20	—	—	—	—	—	—	6	24	—	2	—	—	—
7266	4°50′ S.L. ×111°24′ E.L.	58	5	33	1	6	—	—	—	3	—	22	—	—	6	—	—	—	5	14	—	5	—	—	—

APPENDIX—CONTRIBUTION TO THE SEDIMENTARY PETROLOGY OF THE SUNDA-SHELF—(*continued*)

Sample	Location	Opaque	Transparent minerals in mutual percentages																								
			Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz
7260	5°29′ S.L. ×110°46′ E.L.	65	11	29	—	5	1	—	—	2	1	39	—	—	—	—	—	—	2	6	1	3	—	—	—
7259	5° 9′ S.L. ×110°40′ E.L.	66	11	53	1	5	1	—	—	1	—	13	—	—	1	—	—	1	2	4	1	6	—	—	—
7258	4°50′ S.L. ×110°35′ E.L.	65	12	26	—	7	1	—	—	1	—	24	—	—	4	—	—	—	5	—	—	20	—	—	—
7257	4°32′ S.L. ×110°28′ E.L.	65	12	31	—	4	2	—	—	1	—	28	—	—	12	—	—	—	10	—	—	—	—	—	—
7256	4°12′ S.L. ×110°22′ E.L.	65	16	36	—	5	1	—	—	3	—	22	—	—	5	—	—	—	11	1	—	—	—	—	—
7255	4°12′ S.L. ×110° E.L.	82	11	45	—	2	1	—	—	1	—	33	—	—	1	—	—	—	3	—	3	—	—	—	—
7254	4°12′ S.L. ×109°36′ E.L.	72	10	58	—	3	—	—	—	5	—	21	—	—	—	—	—	—	3	—	—	—	—	—	—
7253	4°30′ S.L. ×109°31′ E.L.	73	8	51	—	10	1	—	—	2	—	14	—	—	2	—	—	—	9	—	1	2	—	—	—
7252	4°50′ S.L. ×109°25′ E.L.	67	6	52	—	6	2	—	—	2	—	18	—	—	1	—	—	—	3	3	—	7	—	—	—
7229	3°50′ S.L. ×108°43′ E.L.	64	10	45	2	4	2	—	—	—	—	17	—	—	6	—	—	—	10	—	1	3	—	—	—
7228	3°46′ S.L. ×109° 3′ E.L.	60	16	58	—	4	1	—	—	—	—	17	—	—	—	—	—	—	2	—	1	1	—	—	—
7227	3°37′ S.L. ×109°23′ E.L.	78	7	35	—	3	2	—	—	2	—	34	—	—	5	—	—	—	7	4	1	1	—	—	—
7226	3°27′ S.L. ×109°43′ E.L.	69	9	60	—	2	1	—	—	5	—	13	—	—	4	1	—	—	—	1	1	3	—	—	—
	BORNEO GROUP type II																								
7316	1°40′ S.L. ×107°56′ E.L.	64	12	44	—	7	3	—	—	1	—	15	—	—	7	—	—	—	8	1	—	2	—	—	—
7317	1°34′ S.L. ×108°19′ E.L.	45	16	16	—	7	9	—	—	3	—	33	1	—	10	—	—	—	5	—	—	—	—	—	—
7318	1°20′ S.L. ×108°35′ E.L.	61	10	31	—	7	4	—	—	2	—	34	—	—	5	—	—	—	4	1	—	2	—	—	—
7319	1° 9′ S.L. ×108°49′ E.L.	66	18	23	—	5	7	—	—	1	—	38	1	—	7	—	—	—	—	—	—	—	—	—	—
7320	0°51′ S.L. ×108°59′ E.L.	61	2	19	—	5	15	—	—	4	—	21	1	—	18	—	—	—	5	—	—	1	—	—	—
7321	0°57′ S.L. ×108° 2′ E.L.	49	7	27	—	9	18	—	2	1	—	7	1	—	13	—	—	—	11	3	—	1	—	—	—
7322	0°33′ S.L. ×108°42′ E.L.	64	6	28	—	10	11	—	—	2	—	36	1	—	4	—	—	—	2	—	—	—	—	—	—
7323	0°26′ S.L. ×108°21′ E.L.	60	18	30	—	6	11	—	—	1	—	32	1	—	1	—	—	—	—	—	—	—	—	—	—
7714	0°27′ N.L. ×108°18′ E.L.	68	6	31	—	8	5	—	—	1	—	29	1	—	10	—	—	—	9	—	—	—	—	—	—
7715	0°26′ N.L. ×108°42′ E.L.	52	17	26	—	4	5	—	—	—	—	41	—	—	3	—	—	—	4	—	—	—	—	—	—
7343	0°55′ N.L. ×108°43′ E.L.	65	10	27	—	3	—	—	—	3	—	38	—	—	8	1	—	—	10	—	—	—	—	—	—
7716	1°48′ N.L. ×108°47′ E.L.	75	7	25	3	—	5	—	—	4	—	34	—	3	8	—	—	—	3	—	—	5	—	3	—
7718	1°46′ N.L. ×108°30′ E.L.	76	16	25	1	5	5	—	1	1	—	22	—	—	15	—	—	—	8	1	—	—	—	—	—
7719	1°44′ N.L. ×108° 8′ E.L.	55	9	24	—	6	7	—	—	—	—	35	—	—	9	—	—	—	4	2	—	4	—	—	—
7350	1°40′ N.L. ×107°16′ E.L.	65	6	40	—	4	—	—	—	1	—	26	—	—	9	—	—	—	12	—	—	2	—	—	—
7349	1°41′ N.L. ×107°36′ E.L.	57	9	23	—	1	—	—	—	2	—	62	—	—	1	—	—	—	2	—	—	—	—	—	—
7348	1°45′ N.L. ×107°56′ E.L.	60	5	38	—	2	—	—	—	1	—	24	—	—	9	—	—	—	16	—	—	5	—	—	—
	MERATUS-P. LAUT GROUP																								
7297	4°20′ S.L. ×114°51′ E.L.	76	22	57	—	7	1	—	—	4	—	6	—	—	—	—	—	—	1	—	—	1	—	1	—
7298	4°31′ S.L. ×115°10′ E.L.	71	8	59	—	12	1	—	—	5	1	7	1	—	2	—	—	—	1	—	—	—	—	3	—
7299	4°41′ S.L. ×115°26′ E.L.	70	14	39	—	9	4	—	—	3	—	7	—	—	4	—	—	5	5	1	1	—	—	8	—
7302	4°36′ S.L. ×116°17′ E.L.	66	3	46	—	17	4	—	—	1	—	3	—	—	10	—	—	2	1	2	—	—	—	11	—
8338	4°51′ S.L. ×116°17′ E.L.	75	10	61	—	13	—	—	—	—	—	3	—	—	9	—	—	3	—	1	—	—	—	—	—
7288	5°32′ S.L. ×114°33′ E.L.	60	4	19	—	8	10	—	—	4	—	11	—	—	20	—	—	3	1	12	—	3	—	5	—
7301	4°21′ S.L. ×116°17′ E.L.	84	5	10	—	2	—	—	—	—	—	—	—	—	40	30	—	—	1	1	—	2	—	9	—
8336	4°47′ S.L. ×115°51′ E.L.	61	5	21	—	2	—	—	—	2	—	—	—	—	63	—	—	—	—	7	—	—	—	—	—
7300	4°50′ S.L. ×115°42′ E.L.	60	3	16	2	2	—	—	—	—	—	2	—	—	55	—	—	—	1	8	—	2	—	9	—

APPENDIX—CONTRIBUTION TO THE SEDIMENTARY PETROLOGY OF THE SUNDA-SHELF—(*continued*)

Sample	Location	Opaque	Transparent minerals in mutual percentages																								
			Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hyperathene	Orthite	Picotite	Topaz
	TRANSITION between BORNEO—GROUP I and MERATUS-P. LAUT GROUP																								
8321	5°45′ S.L. ×112°44′ E.L.	63	10	29	1	1	—	—	—	7	—	29	—	—	15	—	—	—	—	7	—	—	—	1	—
8323	5°33′ S.L. ×112°54′ E.L.	38	3	3	3	—	—	—	—	5	1	11	—	—	20	—	—	—	51	3	—	—	—	—	—
8324	5°25′ S.L. ×112°56′ E.L.	59	2	9	—	—	—	—	—	3	—	61	—	—	23	—	—	—	1	—	—	—	—	—	1
8327	5°20′ S.L. ×113° 4′ E.L.	70	1	13	—	1	—	—	—	4	—	72	—	—	7	—	—	—	2	—	—	—	—	—	—
7295	4°42′ S.L. ×113°30′ E.L.	70	18	48	—	4	2	—	—	4	1	20	—	—	1	—	—	1	—	—	1	—	—	—	—
8329	4°47′ S.L. ×113°27′ E.L.	70	5	14	—	5	—	—	—	14	—	62	—	—	—	—	—	—	—	—	—	—	—	—	—
7294	5° 5′ S.L. ×113°30′ E.L.	60	4	60	1	11	—	—	—	12	—	7	—	—	1	—	—	1	2	—	1	—	—	—	—
7280	5°38′ S.L. ×113°21′ E.L.	64	13	26	—	7	—	—	—	18	—	22	—	1	8	—	—	6	—	—	2	—	—	—	—
7281	5°55′ S.L. ×113°35′ E.L.	69	7	6	—	6	1	—	—	17	—	26	—	—	7	—	—	7	9	6	—	8	—	—	—
8330	4°49′ S.L. ×113°42′ E.L.	64	9	22	—	10	—	—	—	9	—	34	—	—	14	—	—	2	—	—	—	—	—	—	—
7293	4°55′ S.L. ×113°54′ E.L.	65	5	45	—	10	—	—	—	13	—	22	—	—	2	—	—	1	2	—	—	—	—	—	—
8331	4°53′ S.L. ×113°58½′ E.L.	60	15	23	—	6	—	—	—	10	1	37	—	—	5	—	—	3	—	—	—	—	—	—	—
7292	4°47′ S.L. ×114°15′ E.L.	69	1	68	—	11	—	—	—	9	—	10	—	—	1	—	—	—	—	—	—	—	—	—	—
8332	4°55′ S.L. ×114°11′ E.L.	78	3	49	—	6	—	—	—	20	—	14	—	1	3	—	—	2	—	1	—	1	—	—	—
7291	4°36′ S.L. ×114°40′ E.L.	70	3	53	—	10	—	—	—	11	—	18	—	—	2	—	—	1	2	—	—	—	—	—	—
7290	4°54′ S.L. ×114°43′ E.L.	73	7	20	1	11	2	—	—	24	—	24	—	—	2	—	—	2	2	4	—	1	—	—	—
7928	5° 7′ S.L. ×114°27′ E.L.	62	7	18	—	14	8	—	—	6	—	16	—	—	4	—	—	—	2	18	—	3	—	4	—
7269	5°15′ S.L. ×114°39′ E.L.	40	4	36	—	11	—	—	—	3	—	21	—	—	2	—	—	2	4	6	1	10	—	—	—
	S.- CHINA SEA GROUP																								
7357	1°24′ N.L. ×104°53′ E.L.	50	12	46	—	3	1	—	—	—	—	15	—	—	7	—	—	—	15	—	—	1	—	—	—
7332	0° 2′ N.L. ×105°10′ E.L.	63	13	59	—	2	—	1	—	2	—	3	—	—	9	—	—	—	3	—	—	6	—	—	—
7333	0°12′ N.L. ×105°27′ E.L.	61	13	31	—	—	—	—	—	4	—	5	—	—	10	2	—	—	18	1	—	15	—	—	—
7703	0°15′ S.L. ×105°28′ E.L.	75	12	27	4	3	2	—	1	—	—	3	—	—	30	—	—	—	13	—	—	5	—	—	—
7331	0°12′ S.L. ×105°39′ E.L.	61	14	43	—	1	1	—	—	1	—	7	—	—	20	—	—	—	9	—	—	3	—	—	—
7707	0°13′ S.L. ×105°41′ E.L.	52	16	12	5	2	7	—	—	1	—	4	—	—	33	—	—	—	17	—	—	3	—	—	—
7708	0° 3′ S.L. ×105°55′ E.L.	56	15	14	2	2	4	—	1	—	—	4	—	—	40	—	—	—	15	—	—	3	—	—	—
7700	0°48′ S.L. ×106°17′ E.L.	80	11	33	1	7	10	—	—	—	—	1	—	—	23	3	—	—	6	1	—	4	—	—	—
7699	0°47′ S.L. ×106°35′ E.L.	71	8	25	1	5	14	—	—	—	—	1	—	—	15	—	—	—	22	—	—	9	—	—	—
7356	1°25′ N.L. ×105°18′ E.L.	52	6	29	—	4	—	—	—	—	—	11	—	—	4	—	—	—	39	—	—	6	—	—	—
7355	1°26′ N.L. ×105°36′ E.L.	53	4	28	—	3	2	—	—	—	—	10	—	—	16	2	—	—	28	1	—	6	—	—	—
7728	0°47′ N.L. ×105°26′ E.L.	60	5	14	3	2	5	—	1	—	—	7	—	—	19	3	—	—	27	1	—	13	—	—	—
7727	1° 0′ N.L. ×105°39′ E.L.	62	17	35	2	2	5	—	—	1	1	6	—	—	11	—	—	—	16	—	—	3	—	1	—
7334	0°22′ N.L. ×105°45′ E.L.	55	9	12	1	2	—	—	—	1	—	8	—	—	22	7	—	—	28	—	—	10	—	—	—
7335	0°35′ N.L. ×106° 1′ E.L.	76	17	59	—	2	—	—	—	—	—	2	—	—	10	1	—	—	6	—	—	3	—	—	—
7329	0° 1′ S.L. ×106°14′ E.L.	73	16	38	—	1	1	—	—	3	—	7	—	—	18	—	—	—	10	—	—	6	—	—	—
7328	0° ×106°35′ E.L.	78	12	70	—	1	1	—	—	—	—	2	—	—	6	—	—	—	6	—	—	2	—	—	—
7710	0°50′ N.L. ×106°40′ E.L.	86	21	38	—	1	10	—	—	1	—	3	—	—	11	—	—	—	7	1	—	6	—	1	—
7711	0°45′ N.L. ×106°56′ E.L.	85	12	18	2	4	8	—	—	—	—	4	—	—	12	—	—	—	19	4	—	16	—	1	—
7726	1°58′ S.L. ×105°59′ E.L.	85	20	22	1	4	6	—	—	—	—	4	—	—	25	—	—	—	9	1	—	5	—	2	—
7725	1°53′ S.L. ×106°16′ E.L.	85	18	31	1	7	2	—	—	1	—	9	—	—	17	—	—	—	11	—	—	1	—	2	—

APPENDIX—CONTRIBUTION TO THE SEDIMENTARY PETROLOGY OF THE SUNDA-SHELF—(*continued*)

Sample	Location	Opaque	Transparent minerals in mutual percentages																							
			Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz
7336	0°47′ N.L. ×106°17′ E.L.	62	11	27	5	3	—	—	—	—	—	5	—	—	18	4	—	—	24	1	—	2	—	—	—
7337	0°50′ N.L. ×106°39′ E.L.	55	8	46	—	1	—	—	—	1	—	5	—	—	9	2	—	—	26	—	—	2	—	—	—
7712	0°40′ N.L. ×107°18′ E.L.	43	9	5	—	2	2	—	1	—	—	18	—	—	23	—	—	—	37	—	—	2	—	—	—
7353	1°30′ N.L. ×106°15′ E.L.	85	17	22	1	3	—	—	—	—	—	7	—	—	32	—	—	—	16	—	—	2	—	—	—
7724	1°50′ N.L. ×106°32′ E.L.	76	17	25	1	3	7	1	—	—	—	1	—	—	28	—	—	—	11	4	—	1	—	—	—
7723	1°46′ N.L. ×106°51′ E.L.	83	7	23	5	4	8	—	—	1	—	6	—	—	35	1	—	—	9	1	—	—	—	—	—
7338	0°50′ N.L. ×107° E.L.	79	4	24	—	1	—	—	—	—	—	6	—	—	15	8	—	—	12	1	—	29	—	—	—
7352	1°37′ N.L. ×106°36′ E.L.	70	3	64	—	—	1	—	—	—	—	8	—	—	9	—	—	—	9	1	—	5	—	—	—
7351	1°38′ N.L. ×106°56′ E.L.	77	9	29	1	1	1	—	—	1	—	8	—	—	29	—	—	—	19	1	—	1	—	—	—
7345	1°34′ N.L. ×108°46′ E.L.	80	8	49	1	6	—	—	—	1	—	8	—	—	22	1	—	—	4	—	—	—	—	—	—
7722	1°46′ N.L. ×107° 9′ E.L.	50	2	9	1	4	6	—	—	—	—	3	1	—	33	—	—	—	36	3	—	2	—	—	—
7339	0°50′ N.L. ×107°21′ E.L.	58	5	43	3	2	—	—	—	1	—	8	—	—	26	—	—	—	7	—	—	5	—	—	—
7721	1°43′ N.L. ×107°30′ E.L.	52	8	14	1	3	12	—	—	1	—	20	1	—	19	—	1	—	16	1	—	2	—	—	—
7720	1°44′ N.L. ×107°49′ E.L.	65	8	33	—	8	7	—	—	1	—	20	—	—	13	—	—	—	9	—	—	—	1	—	—
7341	0°51′ N.L. ×108° 1′ E.L.	58	4	53	—	5	—	—	—	1	—	15	—	—	15	—	—	—	7	—	—	—	1	—	—
7340	0°49′ N.L. ×107°42′ E.L.	53	2	7	—	—	—	—	—	1	—	21	—	—	27	1	—	—	41	—	—	—	—	—	—
7326	0° 5′ S.L. ×107°16′ E.L.	78	11	18	—	4	1	—	—	5	—	36	1	—	14	—	—	—	7	1	—	2	—	—	—
7713	0°59′ N.L. ×107°37′ E.L.	58	9	8	—	3	11	—	—	—	—	25	—	—	22	—	—	—	20	—	—	2	—	—	—
7325	0°12′ S.L. ×107°38′ E.L.	55	7	19	—	7	11	—	—	—	—	16	—	—	20	—	—	—	25	2	—	3	—	—	—
7324	0°19′ S.L. ×108° E.L.	54	1	29	1	6	4	—	1	3	—	13	—	—	28	—	—	—	10	—	1	2	—	1	—
	MALACCA GROUP																								
7730	1°32′ N.L. ×103° 8′ E.L.	45	10	59	—	8	17	—	1	—	—	1	—	—	3	—	—	—	1	—	—	—	—	—	—
7361	1°26′ N.L. ×103° 7′ E.L.	58	8	32	—	1	—	—	—	—	—	9	—	—	8	—	—	—	28	1	—	13	—	—	—
7360	1°15′ N.L. ×103°24′ E.L.	44	7	22	—	—	—	—	—	—	—	5	—	—	16	2	—	—	15	1	—	33	—	—	—
7358	1°30′ N.L. ×104°38′ E.L.	39	4	10	1	2	—	—	—	1	—	7	—	—	11	3	—	—	19	7	—	35	—	—	—
7359	1°20′ N.L. ×104°24′ E.L.	28	—	2	1	—	—	—	—	—	—	2	—	—	3	4	—	—	37	3	—	48	—	—	—
7374	0°15′ N.L. ×103°54′ E.L.	34	15	5	1	3	10	—	—	—	—	1	—	—	6	—	—	—	22	9	—	27	—	1	—
7706	0°31′ N.L. ×104°41′ E.L.	67	13	13	4	1	5	—	—	2	—	3	—	—	13	—	—	—	32	—	—	14	—	—	—
7375	0° 5′ S.L. ×103°59′ E.L.	29	1	5	—	—	—	—	—	—	—	—	—	—	1	—	—	—	68	3	—	22	—	—	—
7705	0°45′ N.L. ×104°53′ E.L.	60	12	25	1	1	2	—	—	1	—	4	—	—	8	—	—	—	44	—	—	2	—	—	—
7377	0°43′ S.L. ×104° 6′ E.L.	49	3	9	1	—	—	—	—	—	—	—	—	—	—	—	—	—	33	5	—	49	—	—	—
7747	0°56′ S.L. ×104°24′ E.L.	80	—	8	2	—	—	—	—	—	—	—	—	—	14	—	—	—	25	2	—	49	—	—	—
7378	0°56′ S.L. ×104°51′ E.L.	59	10	41	—	2	—	—	—	—	—	10	—	—	9	—	—	—	12	1	—	15	—	—	—
7749	0°58′ S.L. ×105°10′ E.L.	72	18	23	2	3	10	—	—	—	—	2	—	—	23	—	—	—	13	1	—	5	—	—	—
7379	0° 7′ S.L. ×105°30′ E.L.	55	9	66	—	—	—	—	—	—	—	3	—	—	12	—	—	—	6	—	1	4	—	—	—
7702	0°28′ S.L. ×105°33′ E.L.	55	1	4	3	2	2	—	—	—	—	1	—	—	25	—	—	—	40	2	—	19	1	—	—
7701	1°14½′ N.L. ×105°55½′ E.L.	46	2	3	3	1	1	—	—	—	—	1	—	—	30	—	—	—	21	2	—	36	—	—	—
7380	1°23′ S.L. ×105°24′ E.L.	42	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10	24	—	64	—	—	—
7381	1°43′ S.L. ×105°11′ E.L.	57	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	15	—	77	—	—	—
7382	2° 2′ S.L. ×105° 1′ E.L.	23	1	4	1	—	—	—	—	—	—	—	—	—	12	—	—	—	25	25	—	32	—	—	—
7314	2°10′ S.L. ×107°32′ E.L.	60	12	15	—	6	8	—	1	2	—	11	—	—	21	—	—	—	15	1	—	8	—	—	—

APPENDIX—CONTRIBUTION TO THE SEDIMENTARY PETROLOGY OF THE SUNDA-SHELF—(*continued*)

Sample	Location	Opaque	Transparent minerals in mutual percentages																								
			Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Saussurite	Actinolite	Glaucophane	Hornblende	Augite	Enstatite	Hypersthene	Orthite	Picotite	Topaz
	BANKA-BILLITON GROUP																								
7734	3° 9′ N.L. × 99°53′ E.L.	68	59	23	1	3	6	—	—	—	—	—	—	—	1	—	—	—	6	—	—	1	—	—	2
7368	3°56′ N.L. ×100°11′ E.L.	60	63	24	—	—	—	—	—	—	—	4	—	—	2	—	—	—	3	1	—	1	—	—	2
7367	3°56′ N.L. ×100°31′ E.L.	70	53	30	1	—	1	—	—	—	—	2	—	—	3	—	—	—	3	—	—	2	—	—	2
7733	3°24′ N.L. ×100°38′ E.L.	63	53	29	—	—	—	—	—	—	—	2	—	—	2	—	—	—	12	—	—	2	—	—	—
7366	3°18′ N.L. ×100°43′ E.L.	68	40	42	—	—	—	—	—	1	—	5	—	—	5	—	—	—	4	—	—	1	—	—	2
7365	2°13′ N.L. ×101°57′ E.L.	76	32	54	—	2	1	—	—	—	—	1	—	—	6	—	—	—	2	—	—	—	—	—	2
7364	2° 1′ N.L. ×102°13′ E.L.	58	34	48	—	2	1	—	—	1	—	3	—	—	4	1	—	—	4	—	—	2	—	—	—
7383	2°24′ S.L. ×105°43′ E.L.	51	22	59	—	2	—	—	—	—	—	—	—	—	1	—	—	—	2	4	—	10	—	—	—
7384	2°42′ S.L. ×105°50′ E.L.	48	54	35	—	1	—	—	—	—	—	1	—	—	2	—	—	—	1	2	—	4	—	—	—
7385	2°56′ S.L. ×106° 6′ E.L.	65	34	53	1	3	—	—	—	—	—	3	—	—	3	—	—	—	2	—	—	1	—	—	—
7386	3°10′ S.L. ×106°21′ E.L.	68	28	22	—	5	—	—	—	2	—	1	—	—	5	—	—	—	12	13	—	12	—	—	—
7225	3°19′ S.L. ×106°29′ E.L.	82	26	50	—	4	2	—	—	3	—	1	—	—	8	—	—	—	5	1	—	—	—	—	—
7309	3°53′ S.L. ×106°39′ E.L.	83	27	65	—	1	—	—	—	1	—	1	—	—	1	—	—	—	2	—	—	2	—	—	—
7310	3°33′ S.L. ×106°38′ E.L.	74	24	64	—	4	—	—	—	1	—	1	—	—	1	—	—	—	3	—	—	2	—	—	—
7311	3°13′ S.L. ×106°45′ E.L.	80	29	54	—	2	11	—	1	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
7312	2°32′ S.L. ×106°58′ E.L.	65	31	52	—	2	9	—	—	—	—	3	—	—	1	—	—	—	2	—	—	—	—	—	—
7313	2°24′ S.L. ×107°19′ E.L.	75	25	48	—	7	7	—	—	—	—	11	—	—	1	—	—	—	1	—	—	—	—	—	—
7234	4°11′ S.L. ×106°58′ E.L.	84	15	52	—	8	3	—	—	—	—	6	—	—	1	—	—	—	1	5	—	9	—	—	—
4689	4° S.L. ×107°30′ E.L.	70	19	59	—	6	—	—	—	4	1	6	—	—	3	—	—	—	2	—	—	—	—	—	—
7363	1°50′ N.L. ×102°38′ E.L.	56	40	37	—	1	5	—	—	—	—	—	—	—	6	—	—	—	11	—	—	—	—	—	—
7362	1°30′ N.L. ×102°47′ E.L.	71	27	40	2	2	—	—	—	—	—	5	—	—	14	—	—	—	8	1	—	1	—	—	—
7742	0°27′ N.L. ×103°44′ E.L.	47	21	35	—	6	12	—	—	—	—	6	—	—	4	—	—	—	5	2	—	8	1	—	—
7372	0°52′ N.L. ×103°35′ E.L.	85	30	16	—	12	12	—	—	—	—	—	—	—	6	—	—	—	6	4	—	10	2	—	2
7376	0°27′ S.L. ×103°58′ E.L.	52	28	8	—	—	—	—	—	—	—	2	—	—	8	—	—	—	48	1	—	5	—	—	—
7237	5°47′ S.L. ×106° 3′ E.L.	95	4	87	—	3	1	—	—	—	—	1	—	—	—	—	—	—	1	1	—	2	—	—	—
7219	5°14′ S.L. ×106°39′ E.L.	72	—	80	—	6	—	—	—	—	—	—	—	—	2	—	—	—	2	5	—	5	—	—	—
7220	4°54′ S.L. ×106°33′ E.L.	85	7	80	—	3	1	—	—	—	—	1	—	—	—	—	—	—	4	2	—	2	—	—	—
7306	4°52′ S.L. ×106°42′ E.L.	64	8	73	—	—	3	—	—	1	—	—	—	—	4	—	—	1	1	6	—	2	—	1	—
7221	4°34′ S.L. ×106°27′ E.L.	88	3	84	—	5	2	—	—	—	—	1	—	—	1	—	—	—	—	1	—	3	—	—	—
7307	4°33′ S.L. ×106°41′ E.L.	85	6	80	—	—	1	—	—	—	—	4	—	—	4	—	—	—	3	1	—	1	—	—	—
7224	3°40′ S.L. ×106°20′ E.L.	83	2	75	—	5	1	—	—	3	—	8	—	—	2	—	—	—	3	—	1	—	—	—	—
7233	4° 7′ S.L. ×107°18′ E.L.	64	4	53	—	3	1	—	—	—	—	5	—	—	2	—	—	—	3	2	—	27	—	—	—
7231	4° S.L. ×107°57′ E.L.	75	10	69	—	4	—	—	—	1	—	3	—	—	2	—	—	—	2	—	—	9	—	—	—
7241	4°46′ S.L. ×107°47′ E.L.	48	15	30	—	8	26	—	—	—	—	3	—	—	6	—	—	—	1	4	—	5	—	2	—
7243	4°49′ S.L. ×108°11′ E.L.	48	6	72	1	9	1	—	—	—	—	1	—	—	1	—	—	—	1	3	—	5	—	—	—
4690	5° S.L. ×109°13′ E.L.	63	3	80	—	4	—	—	—	6	—	1	—	—	3	—	—	—	3	—	—	—	—	—	—
7265	5°11′ S.L. ×111°21′ E.L.	63	12	39	10	8	1	—	1	1	—	10	—	—	3	—	—	—	5	6	—	4	—	—	—
7264	5°31′ S.L. ×111°20′ E.L.	70	5	63	—	6	1	—	—	1	—	10	—	—	—	—	—	—	6	6	1	1	—	—	—
7304	5°19′ S.L. ×116°31′ E.L.	70	8	58	—	6	—	—	—	4	—	2	—	—	6	—	—	—	4	2	—	2	—	8	—
	BERHALA GROUP																								
7737	3°40′ N.L. × 99°26′ E.L.	7	—	20	—	—	—	—	—	—	—	—	—	—	2	—	—	—	64	—	—	6	3	—	—
7738	3°33′ N.L. × 99°34′ E.L.	1	—	3	—	—	—	—	—	—	—	—	—	—	1	—	—	—	79	—	—	2	15	—	—
7739	3°23′ N.L. ×100° E.L.	25	18	8	—	—	—	—	—	—	—	—	—	—	6	—	—	—	49	—	—	7	12	—	—
7740	3°15′ N.L. ×100°24′ E.L.	45	33	12	3	1	—	—	1	—	—	2	—	—	11	—	—	—	29	—	—	2	6	—	—
7369	3°57′ N.L. × 99°31′ E.L.	36	20	37	—	2	—	—	—	—	—	—	—	—	13	—	—	—	32	1	—	5	—	—	—

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FIGS. 1, 2, DECEMBER, 1950

HEAVY RESIDUES FROM LOWER TRIASSIC CONGLOMERATES, NEW SOUTH WALES

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ABSTRACT

Heavy mineral residues from the matrix of the basal conglomeratic beds of the northeastern part of the lower Triassic deposition basin in New South Wales (Australia) are described, with particular reference to the varietal features of the individual minerals. The assemblages are compared with those from other parts of the lower Triassic and with those from upper Permian beds. It is suggested that several petrographical provinces contributed to the matrix of the conglomerates.

INTRODUCTION

Rocks of Triassic age are strongly developed in New South Wales and are divided into three well-defined series; Narrabeen (at the base, equivalent to the Lower Triassic, Bunter), Hawkesbury, and Wianamatta. The lowest part of the Narrabeen lies conformably on the Permian (Raggatt, 1938), and the Narrabeen basin developed by gradual uplift of the surrounding areas. The extent of this basin in shown in figure 1. The Narrabeen Series consists, in the deeper parts of the basin, of fine sandstones, shales, and tuffaceous shales, but is conglomeratic near the edges, particularly the northern and north eastern edges. It was described by David (1932) thus: "The old shore-line of this lake (Narrabeen) is strongly marked on the north east from near Newcastle to Murrurundi at which place the basal conglomerates are coarse and some 200 ft. in thickness. The abundance of red jaspers among the pebbles shows that the rivers which formed these conglomerates drained off the highlands of New England" (to the north and northeast). Cliffs of these lower Narrabeen conglomerates are prominent along the western side of the Upper Hunter River Valley (fig. 2), the height varying from about 200 ft. at Murrurundi to 700 ft. or more west of Muswellbrook.

The conglomerate beds have been described by Raggatt (1938), Dulhunty (1939), and Carroll, Brewer, and Harley (1949). The conglomerates are massive with a fine-grained, firmly cemented, clayey matrix in which are set pebbles, varying in size from 3 to over 25 mm (average, 12 mm) in diameter, of jasper, chalcedony, sandstone, and quartz.

Samples of the conglomerate were collected from the top, middle, and base of the bed at the localities shown in figure 2. The heavy residues of the matrix are described to give information of a regional character concerning the different sedimentary petrological provinces (if any) and zones as defined by Doeglas (1940). The heavy residues are also compared with those described by Culey (1932) from other parts of the Narrabeen basin.

METHOD OF EXAMINATION

The original large field samples were crushed and quartered down, the pebbles being removed. The fine grained matrix was separated in bromoform to obtain the heavy residues, the grade of material separated being from 0.12 to 0.06 mm in diameter. Only very small quantities of heavy residue were obtained from all the samples. As the residues had to be boiled in HCl to remove ferruginous and other coating material, no figures are given for the quantity of residue; it

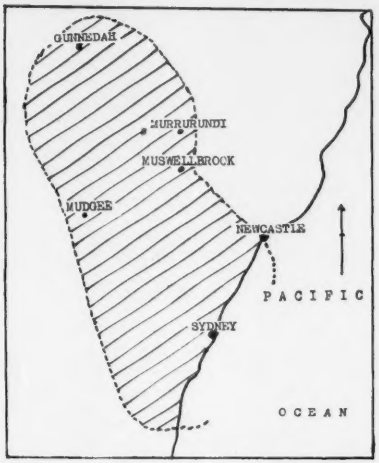

FIG. 1.—Locality map of part of New South Wales indicating the extent of the deposition basin in Narrabeen (lower Triassic) time. (Published by courtesy of Dr. H. G. Raggatt.)

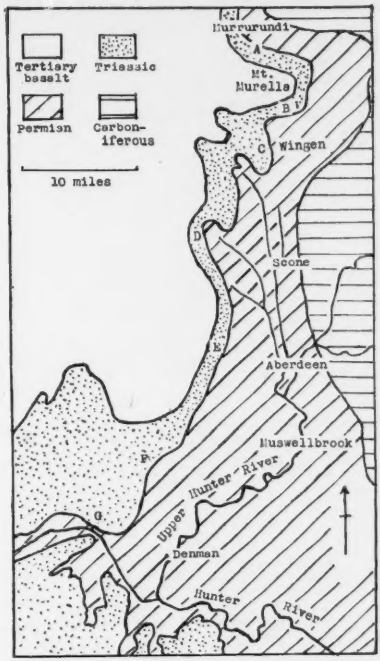

FIG. 2.—Geological sketch-map of part of the Upper Hunter River Valley, New South Wales, showing the eroded edge of lower Narrabeen (Triassic) conglomerate and localities from which samples were obtained (A, B, etc.).

would have been less than 0.1 per cent of the matrix, which formed a variable proportion by weight of the conglomerate samples, ranging from 22 to over 90 per cent in a number of the samples examined. The sample localities are given in figure 2 and described in table 1.

HEAVY MINERAL RESIDUES

The following heavy minerals were identified from the matrix of the conglomerates; ilmenite, zircon, tourmaline, garnet, anatase, rutile, hornblende, monazite, staurolite, andalusite, sphene, epidote-zoisite, muscovite, corundum, picotite, barite. The distribution of these minerals is given in table 2, but no counts were made as the amount of material was extremely small. The residues appear, at first sight, to be impoverished, but fine clayey material usually does not contain an abundance of heavy minerals, and the matrix of all the conglomerates was clayey, not sandy. The most abundant minerals of the residues were opaque grains (ilmenite and reddish brown limonitic grains; magnetite was present as possibly half a dozen grains to each residue), zircon, and tourmaline. The remainder of the minerals listed can be regarded as accessories only. Varietal features of the individual minerals, which may be of significance in characterizing the residues, are noted below.

Zircon.—Generally in short prismatic grains of several different types:

(a) well-rounded, often with matt surface.
(b) clear, sharp-edged, prismatic grains with well-defined pyramids, generally not rounded or broken, and containing numerous inclusions, rod-like and clear, or rounded and black opaque.

TABLE 1.—*Description of samples of lower Narrabeen conglomerate*

Sample No.		Locality	Description
N 1		near Murrurundi	Top of cliffs, 120 ft. above ground-level.
N 2	A	Do.	50 ft. above ground-level.
N 3		Do.	3 ft Do.
N 4	B	south of Mt. Murella	Base of cliffs.
N 5	C	west of Wingen	Base of cliffs.
N 6	D	Bunnan Rd. west of Scone.	Base of cliffs.
N 7		Do.	Do. (sandstone).
N 8		west of Aberdeen	Top of cliffs.
N 9	E	Do.	Do. (sandstone).
N 10		Do.	80 ft. below top of cliffs.
N 11		Do.	Base of cliffs (coarse sandstone).
N 12	F	8 miles northeast of Sandy Hollow	Base of cliffs.
N 13		Denman-Merriwa road	Top of cliffs.
N 14	G	Do.	Half-way up cliffs.
N 15		Do.	Base of cliffs.

(c) similar in habit to (b) but with fine zoning near the edges; zoning does not extend to the center of the grains.

Colored grains are inconspicuous, and no purple zircon was seen. A few grains of class (b) are a very pale brown, but are not pleochroic.

Tourmaline.—Several types occur:

(a) ragged, striated, broken, prismatic grains generally gray in color.

(b) clear broken fragments, gray, or more rarely, blue in color.

(c) rare blue/brown particolored, broken grains.

(d) well-rounded gray or brown grains.

Of these types (a) is the most common.

Garnet.—When present garnet occurs in pinkish brown and colorless grains of irregular shape, a few only showing slight rounding. One grain with a characteristic pitted surface was noted.

Rutile.—This mineral is not plentiful in these residues. It occurs in deep reddish brown, well-rounded grains and as occasional yellow rounded grains. No grains of ilmenite altering to rutile were observed. Rutile appears to be all detrital and not authigenic.

Anatase.—Authigenic anatase was found in a number of the residues as very small yellow tablets, the less common octahedral habit occurring in sample N 14 only.

Amphibole.—A few worn brownish green grains of amphibole referable to hornblende and a few colorless grains with $Z \wedge c = 15° \pm$ were present. The latter was more plentiful than hornblende.

Monazite.—Typical rounded monazite occurs in sample N 8 which is somewhat more sandy than some of the other samples, and in N 15 which mineralogically appears to be a somewhat different type of sediment. Monazite is not plentiful.

Sphene.—In colorless to pale yellow-brown, irregular grains sphene is fairly common, but never constitutes a major constituent.

Epidote-zoisite.—Grains of rather pale epidote showing gradations to zoisite occur in a number of the residues.

Corundum.—Typical patchy blue irregular grains of corundum occur in two samples, N 11 and N 15, from the basal part of the conglomerate in widely separated localities.

Picotite.—An almost opaque mineral occurring in samples N 13–15 was identified as

TABLE 2.—*Minerals present in the heavy residues of the lower Narrabeen conglomerates*

Locality	A			B	C	D		E				F	G		
Sample No.	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15
Situation	T	M	B	B	B	B	B	T	T	M	B	B	T	M	B
Opaques	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Zircon	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Tourmaline	+			+	+	+	+	+	+	+	+	+		+	+
Rutile				+	+		+			+	+			+	+
Garnet						+					+			+	+
Amphibole							+					+			+
Monazite								+							+
Sphene				+		+			+		+	+		+	+
Epidote-zoisite							+		+		+				
Corundum												+			+
Picotite													+	+	+
Staurolite								+	+						
Andalusite									+						+
Barite				+					+			+			
Muscovite								+						+	
Anatase				+		+				+	+			+	

Localities: A, Murrurundi; B, Mt. Murella; C, Wingen; D, Scone; E, Aberdeen; F, Sandy Hollow; G, Denman-Merriwa Rd.
Situation: T, top of bed; M, middle of bed; B, base of bed.

picotite, and although the residues were carefully searched it could not be identified in other samples. It occurs in irregular grains.

Staurolite.—In sample N 8 typical staurolite was found; one grain shows the common form of corroded ends described as "spires" (Allen, 1949, p. 319). Staurolite is also present in N 9.

Andalusite.—One very small grain of rounded andalusite was found in N 15.

Barite.—Colorless grains identified as barite occur in several of the residues. The grains are irregular in shape, have a high refractive index with a medium birefrigence and straight extinction.

Muscovite.—A little muscovite was found in the residue of N 8.

DISCUSSION OF RESULTS

The lower part of the Triassic in this part of New South Wales has been divided by Dulhunty (1939) into a basal conglomeratic portion conformably overlaid by more sandy beds. Typical heavy mineral assemblages from this conglomerate over a lateral distance of approximately fifty miles are given in table 2. There are three localities from which samples representing the base, middle, and top of the conglomerate bed were obtained; viz., Murrurundi, Aberdeen, and Denman-Merriwa road. Of the remaining samples N 4–7 and N 12 are from the base of the conglomerate. Noticeable features are, firstly, the impoverishment of the suite of minerals from the northernmost portion of the bed which is considered to be very near the original edge of the deposition area (Murrurundi) compared with samples from elsewhere in the same bed; and secondly, there is little variation mineralogically within each of the three vertical sections.

With regard to the individual minerals the points to be noted are:

(1) The zircon and tourmaline types are similar throughout.

(2) There is a notable absence of purple zircon which is fairly common in the residues from Permian sediments. The zoned grains are the only type of zircon which are in any way comparable with those from the Permian.

(3) The tourmaline types are similar to those described by Culey (1938) and Carroll (1940) from Permian sediments.

(4) Several minerals such as staurolite, corundum, and picotite are confined to one vertical section of the beds; this indicates a variation in source of the sediments.

The derivation of the minerals appears to be as follows: zircon has been derived from ancient sedimentary rocks (type a, well-rounded) as well as from igneous rocks; tourmaline is almost exclusively fresh and angular and, therefore, of primary origin; staurolite, andalusite, amphibole, and probably epidote-zoisite, are derived from pre-existing sediments, as is rutile. Garnet appears fresher (and less travelled?) than these minerals. The distributive province was probably mainly fine-grained igneous rock, largely acid, with some sediments. The suite containing picotite, and possibly garnet, came from a different source containing ultrabasic rocks.

Culey (1932) has described the assemblages from a number of samples of the Narrabeen beds from outcrops to the north, south, and west of Sydney from sediments, mostly shales, from the deeper parts of the deposition basin. Minerals recorded as common to all the samples are: rutile, tourmaline, zircon, and picotite. Other minerals fairly common but of sporadic occurrence are: magnetite, anatase, pyrite, calcite or siderite, ilmenite, muscovite, garnet (northern samples only), apatite, spinel, hypersthene, and monazite. Among the zircon green and purple varieties were recorded from near Newcastle.

Mineral assemblages from various Permian beds have yielded the following minerals (Culey, 1938): garnet, magnetite, picotite, pyrites, anatase, rutile, xenotime, zircon, apatite, ilmenite, siderite, tourmaline, barite, brookite, hornblende, and monazite. The distribution and varietal features of these minerals are given. A similar suite of minerals was found by Carroll (1940) and the varietal features discussed. Heavy residues of soils derived from Permian beds in the Upper Hunter River Valley contain similar minerals (Brewer, unpub.). It is probable that the Narrabeen and Permian assemblages previously described have been derived from the erosion of a similar land-mass.

Of the lower Narrabeen assemblages described here samples N 1–12, although yielding a very small quantity of heavy residue, appear to be sufficiently distinct to separate them from the underlying Permian beds. The assemblages from samples N 13–15 appear very similar to those to be expected from Permian sediments, N 15 from the base of the conglomerate particularly so. The presence of staurolite and corundum, and the absence of purple zircon may, however, serve to distinguish them.

If samples from the base of the conglomerate, presumably only a short distance stratigraphically above the Permian, are considered, it is evident from table 2 that variation in the assemblages occurs. In the north (locality A) opaque grains and zircon are the sole constituents; at B, about eight miles south, tourmaline, rutile and sphene appear; and at C the assemblage is similar except that sphene is lacking. At D, about 25 miles south of A, garnet makes its first appearance, as do amphibole and epidote; the same assemblage occurs at E, about 15 miles from D. At F, corundum appears, while at G, monazite and picotite are added to the assemblage. Even from the examination of these few samples it is evident that the sediment was derived from several distributive provinces, although the pebbles in the conglomerate are very similar. It is suspected, however, that the clayey material of the matrix may not have been deposited at quite the same time as the pebbles.

The samples of Narrabeen beds described by Culey (1932) were apparently derived from the erosion of land to the north of Newcastle; as the Permian assemblage is similar, this was also the distributive province for these sediments. The examination of additional samples of both Narrabeen and Permian beds, together with a search for the parent rocks yielding monazite and purple zircon, can be expected to yield information of value with regard to the deposition of the Permian and Lower Triassic.

ACKNOWLEDGMENTS

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FIGS. 1, 2, DECEMBER, 1950

LAMINATED BEACH SAND[1]

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ABSTRACT

The size distribution of sand grains that form laminae in beaches was investigated by a microscopical study of thin-sections of naturally and artificially cemented beach sands. Median diameters of sand in the individual laminae range from much coarser to much finer than the median diameter of the entire sand samples, whereas the sorting coefficients in the individual laminae are generally smaller than for the whole sample.

INTRODUCTION

Sand beaches characteristically consist of alternating layers of coarser and finer sand grains. Generally, the layers range from 1 to 20 mm in thickness and are properly called laminae. They are most apparent where the coarse lamina consist of large light-colored quartz and feldspar grains and the fine lamina is a concentrate of dark heavy minerals, such as magnetite, ilmenite, hornblende, and olivine. In beaches of simple composition, like the quartz-feldspar beach at Daytona, Florida, or the calcium carbonate beaches of coral reefs, the laminae have little color contrast but are still present. The gross characteristics of beach laminae have been described by Thompson (1937) and their origin is believed by Grant (1943) and others to be related to variations in the transporting capacity of waves. Similar laminae in dune sands (Bagnold, 1942, p. 238) probably result from variation in wind velocity.

Sand samples for textural studies of beaches are generally scooped by hand to a depth of about 10 cm. As this depth usually includes several laminae, the sample is essentially a composite or channel sample. The grain-size distribution, therefore, is an average and, while it might be representative of the whole beach, it is not characteristic of any instantaneous set of depositional conditions. For example, either the coarse or the fine lamina alone should be much better sorted than a composite sample that includes both.

A preliminary approach to the study of the laminae was made by scraping thin depth increments from an area 10 to 15 cm in diameter at Scripps Beach, La Jolla, California. The top light-colored layer had a median grain diameter of 0.190 mm, the transitional zone was discarded, and the underlying dark-colored layer had a median grain diameter of 0.165 mm (Emery, 1945). Owing to the difficulty of sampling either lamina without including some sand from the other, the difference between the measured grain sizes of the two laminae is less than that actually existing.

To learn more of the grain-size distribution within the laminae and in the transitional zone, studies of thin-sections cut transverse to the bedding were necessary. Artificial cementing of the sand tightly enough for sectioning, without disturbing it by removal to the laboratory was a major difficulty. This problem was first side-stepped by using naturally cemented beach sands—or beachrock. Such beachrock is common around islands of coral reefs throughout the tropics, where it consists of broken shells, Foraminifera, coral, Lithothamnion, and Halimeda cemented by secondary calcite. Several slabs and thin-sections of slabs from Bikini Atoll were available for this study. Similarly, beachrock composed of ordinary detrital minerals ce-

[1] Contribution of Allan Hancock Foundation. No. 59.

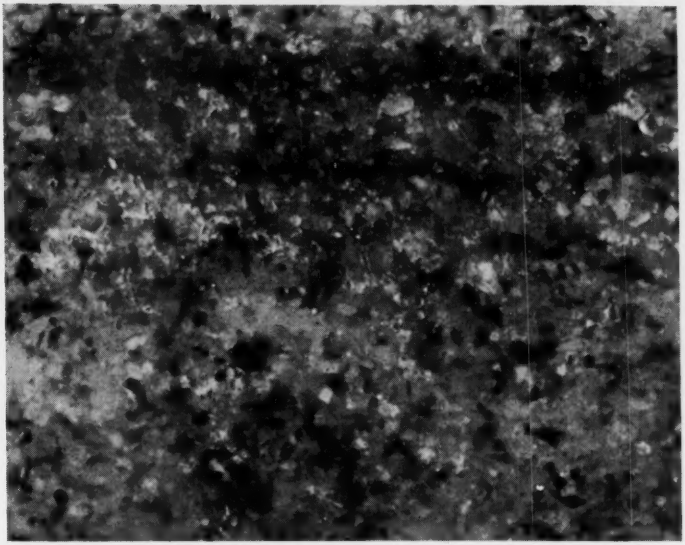

FIG. 1.—Section of artificially cemented beach sand from near Newport Pier extending from surface to depth of five millimeters. Note two thin dark laminae just below surface. Overlapping of grains results from great thickness of section, 300 microns, to improve grain-size determination.

mented by calcite was collected from beaches of Mono Lake, California, and Pyramid Lake, Nevada.

To study loose beach sand, a technique of artificially cementing the grains was developed. The cementing agent must be able to penetrate sand easily, to wet the sand and not be repelled by interstitial water, to harden fairly rapidly, and to be tough enough to hold the grains firmly during sectioning. After several tests with various materials, satisfactory results were obtained by using a commercial plastic called *Castolite*. To 50 cc of *Castolite* was added one or more cc of thinner and two to six drops of a special *Castolite* hardener solution. The amount of thinner required for best results depended on the grain size of the sand; coarse sand even allowed penetration of the fluid plastic without any thinner. The resulting mixture was poured on the sand within an area enclosed by a metal or cardboard ring. A small tin can proved satisfactory. After 20 minutes the plastic was hard enough to permit removal of the sample without disturbance. Final hardening was completed in the laboratory by putting the sample close to a hot light bulb for four to eight hours. In addition to its other advantages, *Castolite* is translucent and colorless, permitting easy measurement of grain diameters.

MEASUREMENTS

Thin-sections of the naturally and the artificially cemented sands were cut fairly thick, about 250 to 400 microns, in order to minimize the errors that would result from failure to include the maximum projection area of the grains. Mounted on the mechanical stage of a petrographic microscope, each section was repeatedly moved across the stage so that an average of 100 grains could be

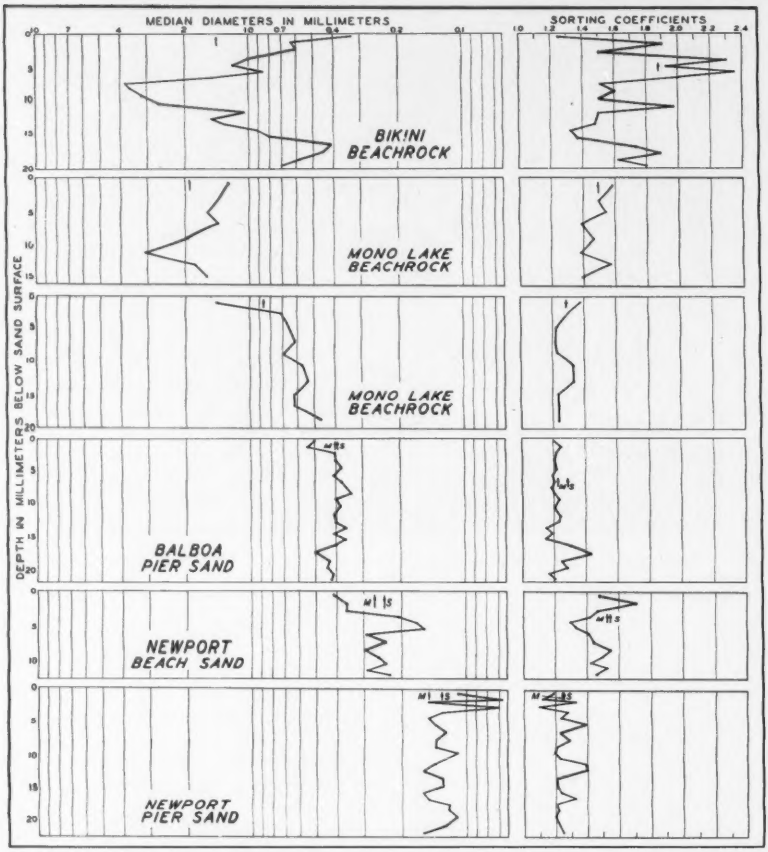

FIG. 2.—Median diameters and sorting coefficients for traverses across six thin-sections of beachrock or artificially cemented beach sand. The arrow with *m* indicates median diameter and sorting coefficient for whole slide determined by microscope; the arrow with *s* is same determined by sieving.

measured in each of 15 to 25 parallel strips 1 mm apart. For the very coarse Mono Lake beachrock this spacing was doubled. All grains that lay within 0.4 mm of the horizontal axis of the micrometer eyepiece were examined. The number of grains having long diameters within the limits of each Wentworth size grade were counted. As this size distribution is based on number of grains rather than on their weight or volume, it is not comparable to the size distribution determined by ordinary mechanical analyses. A conversion to volume distribution was made by multiplying the numerical frequency by the square of the average diameter for each size-grade and assuming the thickness of each grain to be unity. The median grain diameter on this basis of volume percentage for each traverse is presented in figure 2. In addition, the median diameter on a volume

basis for all grains measured in all traverses was computed and compared with the median diameter determined by ordinary sieve analysis of a separate sample of the loose sand. Similarly, sorting coefficients for grains in each traverse, for the whole sample, and for a separate cut analysed by sieving were determined and plotted.

RESULTS

One thin-section of beachrock from Bikini Atoll, two of beachrock from Mono Lake, and three of artificially cemented sand from beaches near Newport, California, were selected for detailed study because they include a range from fine sand to a very coarse sand. In all except the sand from Balboa Beach, field examination showed the presence of laminae near the surface of the beach. They are also well shown by the variation with depth of the median diameters determined by grain counts using a microscope (fig. 2). It is evident that laminae can be present in either fine or coarse sand and that, in at least these examples, coarse sand has thicker laminae than the fine sand. Half of the thin-sections show that the surface lamina is coarser than the underlying one, and half show it to be finer. Usually, the laminae having a finer grain-size contain a much higher percentage of heavy minerals than the adjacent laminae of coarser grain-size. The finer sands show no imbrication whatever and the coarser ones only a slight and uncertain tendency toward imbrication. The over-all median diammeters of all grains measured optically are nearly the same as the median diameters determined by the ordinary technique of sieving and weighing the sand, thus indicating that this optical method of analysis is fairly reliable.

All sorting coefficients are lower than 2.5; thus, the sand belongs to Trask's well-sorted class. In general, the coarsest sand proved to be least well-sorted (2.2) and the finest sand was the best-sorted (1.2). This relationship between sorting and grain-size is in agreement with the conclusions reached by Inman (1949) on the basis of hydrodynamic analysis of the transportation of subaqueous sediments. Examination of figure 1 shows that the sands of the individual traverses are usually better sorted than the thin-section as a whole. Such is to be expected, of course, because a well sorted fine sand and a well-sorted coarse sand mixed together must yield a less well sorted composite sand. Just as for the median diameter, the sorting coefficient determined optically for the whole thin-section closely duplicates the sorting coefficient measured by sieving and weighing.

SIGNIFICANCE

This study verifies the belief that the median grain-sizes and the sorting coefficients determined by ordinary mechanical analyses of scoop samples of sand are composites. They may not, therefore, reflect the relationship of the sand to an instantaneous set of water conditions. Moreover, an entirely different set of percentages of heavy minerals exists in the coarser and in the finer laminae, so it would appear that, in the comparison of beach samples, heavy mineral studies should take into account the relative abundance of thin fine-grained heavy mineral laminae.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 20, NO. 4, PP. 224–226
FIGS. 1, 2, DECEMBER, 1950

SORTING OF CANADIAN RIVER, OKLAHOMA, SANDS

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ABSTRACT

Sorting for certain Oklahoma river sands is similar to that found in dune, beach and marine offshore sands.

Unimodal histograms have been reported from water-deposited sand samples from the North and South Canadian rivers of central Oklahoma.

To verify this, a detailed study of a single river sand bar in the North Canadian was made during the fall and winter of 1949–50. Twenty-four samples were collected in a grid pattern from a river-bank bar about 200 feet long. This sand bar was located immediately west of the State Highway 18 bridge at the southern city limits of Shawnee.

The sand was beginning to dry following a high water stage. The northern edge of the bar (parallel with the current) had already been eroded slightly; a few days later the bar had been removed entirely.

Sorting coefficients varied from 1.15 to 1.60. The average (arithmetic, weighted mean) was 1.28333, the median 1.27 ± 0.03.

A value of 2.5 has been listed as excellent sorting (Trask, 1932). Near-shore marine sands have a sorting coefficient of 1.0 to 2.0, with an average of 1.45 (Hough, 1940). Beach sands have been reported by Krumbein (1936) with a sorting coefficient of 1.22. Sidwell and Tanner (1939), in a study of 34 samples from West Texas sand dunes, found the average sorting to be 1.24. A "typical" river sand analyzed by Udden appears to have a sorting coefficient of 1.6 (Twenhofel, 1932).

With a single exception, the Canadian river bar sands had sorting coefficients below 1.40. The highest frequency encountered was 68 per cent, on the $\frac{1}{8}$ mm screen. The average maximum frequency was 52.4 per cent.

Curves were skewed toward both coarse and fine sizes. The highest symmetry appeared in a curve with skewness of 0.956.

The F:C ratio was 1.5. Keller (1945) reported a ratio for 27 beaches of 1.1, and ratios for various dune areas of 2.5

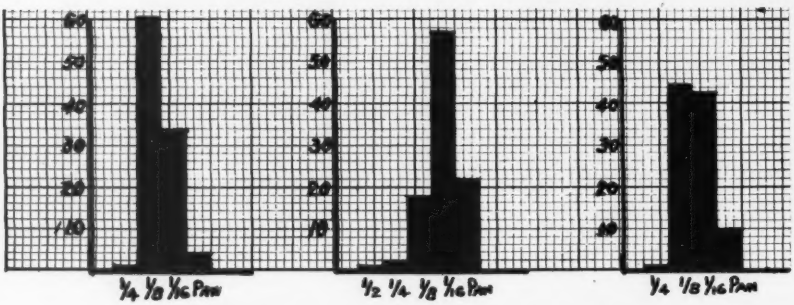

FIG. 1.—Three representative histograms for North Canadian River sands.

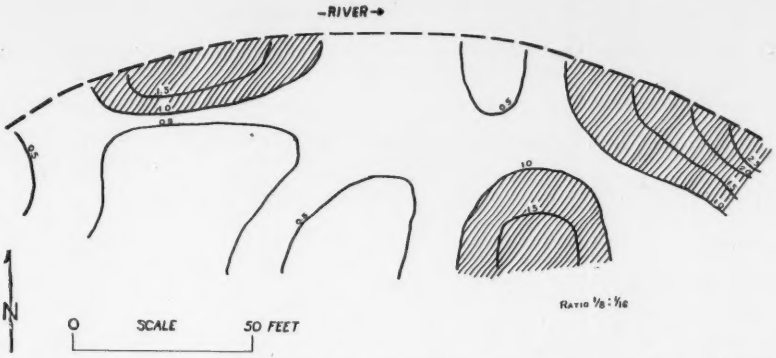

FIG. 2.—Collection points for $\frac{1}{8}$ mm and 1/16 mm grains are shown on the isopleth map. The heavy dashed line represents the northern (water) margin of the sand bar in the North Canadian river. Areas where the larger grains were predominant are shaded.

to 9.4. F:C ratio for West Texas dune sands was 0.33 (Tanner, 1939).

The histograms reveal that rarely did the third most numerous size (usually the pan fraction) exceed 15 per cent. Fourth and fifth sizes, when present, seldom exceeded 5 per cent each.

The two most common sizes were the $\frac{1}{8}$ mm and 1/16 mm fractions. In several samples, the $\frac{1}{8}$ mm fraction represented 60 per cent or more of the total.

Frequency curves for these samples plotted as straight lines on arithmetic probability paper. Each sample, therefore, is thought to represent an unmixed sediment deposited by a current of constant velocity (Doeglas and Smithuyzen, 1941).

Fifteen check samples were taken in an L-shaped pattern on the South Canadian floodplain, immediately below the State Highway 9 bridge southwest of Norman. Ten of these samples were taken in a line parallel with the bridge; the other five were taken in a line parallel with the low-water channel.

The histograms were unimodal. The highest frequency encountered (on the $\frac{1}{8}$ mm screen) was 77.5 per cent. For this sample, sorting was 1.12 and skewness 0.988.

Unlike the 24 taken on a single bar these samples were collected on a braided sand expanse about 1,000 feet wide. In the first case, a single sedimentation unit was involved (Otto, 1938). In the second case, at least a dozen different units were represented. Yet the results were quite similar.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 20, NO. 4, PP. 227–230
FIGS. 1a, 1b, DECEMBER, 1950

AUTHIGENIC ALBITE IN THE GREEN RIVER OIL SHALES

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ABSTRACT

Very small crystals of authigenic albite have been found in those layers of the Green River formation with the highest content of organic matter. The nature of the Green River sediments clearly implies a low temperature of formation for the feldspar and suggests a relation between the organic matter and the authigenic mineral.

INTRODUCTION

The Green River Oil Shales of Colorado are of interest to sedimentary petrologists because of the unusual assemblage of minerals they contain. The Green River formation, of which the oil shales are members sufficiently rich in organic matter to yield petroleum on destructive distillation, is a middle Eocene marlstone in which dolomite is the dominant mineral. In the most complete paper concerning the formation, Bradley (1931) reported that calcite, quartz, orthoclase, and plagioclase, together with the dolomite, are the most abundant minerals. In addition, lesser amounts of pyrite, zircon, sphene, muscovite, and volcanic glass are present. Among the new and unusual minerals, Bradley (1931) recorded the presence of analcite, and studies of the Green River in Wyoming have revealed shortite (Fahey, 1939), northupite, trona, bromlite, searlesite, gaylussite, pirssonite, bradleyite (Fahey, 1941), and loughlinite (Fahey, 1948).

During a recent petrographic examination of the oil shale[1], those layers with the highest organic content (50 to 75 gallons of crude oil per ton) were observed to contain many crystals of a feldspar that has been identified as authigenic albite.

NATURE OF THE ALBITE

The albite appears most frequently as simple rhomb-like crystals greatly flattened on (010). Small prisms generally terminate the acute angle of the rhombs but these are absent from occasional grains (fig. 1a). Measured on the long diagonal, the maximum length of the crystals is about 3 millimeters. The average length is nearer 0.15 millimeter. The average thickness is about one-third the length.

Two indices of the authigenic feldspar, which is biaxial positive, were determined as $N_p = 1.515 \pm$ and $N_g = 1.525 \pm$. Because of the thickness of the grains, the third index could not be measured satisfactorily.

Because the crystals are most generally resting on (010), twinning is not always apparent. On properly oriented grains, simple twinning after the carlsbad law may be seen, with (010) the composition plane (fig. 1b).

The albite shows extinction when the long diagonal is parallel to the crosshairs. Measurement of the extinction on (010) parallel to (001) gives values for the extinction angle of from 15 to 22 degrees. As the microphotograph illustrates (fig. 1b), many of the grains do not show complete extinction on (010). The central areas which may be mineralogically or crystallographically different show extinction different from that of the marginal areas.

Inclusions are abundant in the authigenic crystals. The inclusions are commonly concentrated in a broad band along the short diagonal of the rhomb-like crystals and may be present in sufficient quantity to render the central area nearly

[1] This paper is part of a Master's Thesis presented at Saint Louis University.

FIG. 1a.—Authigenic albite from Green River oil shale: in ordinary light (×70).

opaque. The included matter appears to be chiefly dark-colored carbonaceous matter but may also include flakes of mica. The outer portions of the crystals tend to be free of inclusions and are clear. In reflected light, the albite which is free of included matter appears clear or white in contrast to the amber color of the grains with inclusions.

That the mineral is authigenic cannot be questioned. The sharp angularity of the grains, which under a binocular microscope show excellent crystal development, clearly implies that the crystals have formed in place. Even more compelling is the line separating the nucleus from the rim added by secondary growth. The outer portions of the crystals are generally separated from the central areas by a faint irregular line. That it is a real boundary between material of different composition or optical orientation is shown by the development of the Becke line. The line of demarcation is not well illustrated by the microphotographs. Further evidence of the authigenic nature of the feldspar is seen in comparisons with occurrences of authigenic albite elsewhere. Spencer (1925) has described authigenic albite from a

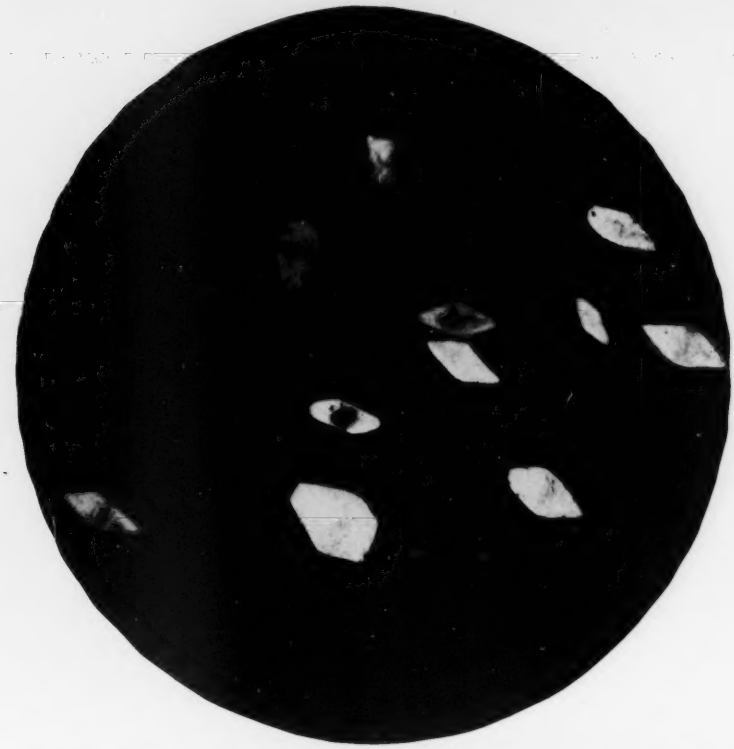

FIG. 1b.—Authigenic albite from Green River oil shale: under crossed nicols (×75).

limestone in India in which the feldspar bears a very close resemblance to the albite found in the Green River shale.

OCCURRENCE

It appears that the authigenic albite is confined to those members of the Green River with the highest organic content. The albite is most abundant in the samples averaging 60 to 75 gallons of crude per ton, although notable amounts are to be found in the 50 gallons per ton sample. None was found in the barren samples. This relationship is borne out by examination of thin sections. The sections of the samples with the highest organic content contain many grains of albite; the sections of the barren rock show no albite.

The authigenic albite in the Green River formation necessarily formed at low temperature. With the possible exception of heat supplied by the decay of vegetable matter, there is no evidence whatsoever that the formation has ever been subjected to any great amount of heat. In fact, the very absence of heat and pressure has been advanced as a possible explanation as to why there has been no distillation of the organic matter

into petroleum. The strata have undergone no folding and are essentially flat-lying for miles in all directions. Metamorphism, which has been suggested in explanation of the formation of authigenic minerals, has never been a factor in Green River history. Furthermore, the Green River formation has never been deeply buried. The only possible source of heat is from the decay of vegetable matter. Although it is true that the occurrence of the authigenic feldspar is confined to those layers having the highest organic content, there is no positive relationship between the heat of decay and the formation of the feldspar. Such a conclusion is supported by the evidence of occurrences of authigenic feldspars elsewhere. Tester and Atwater (1934) concluded that the formation of authigenic feldspar is the result of normal sedimentary processes. The absence of metamorphism in a limestone in which authigenic orthoclase occurred, led Daly (1917) to believe that the feldspar was of low-temperature formation. Similar conclusions have been reached by many others.

Saline waters have been suggested by several investigators as being instrumental in the formation of authigenic feldspars. However, the Green River is believed to be of lacustrine origin in which conditions of salinity were never greatly prevalent. Bradley has indicated that during intervals in the Green River history, Uinta Lake was saline, but even then the conditions of salinity were unlike those to be found in a marine environment.

That the authigenic albite in the organic-rich members of the Green River formation, and in occurrences described by others, is in association with carbonaceous matter would seem to indicate that there is a relationship between organic matter and the development of authigenic feldspars. It may be that acids produced by the decaying organic matter are instrumental in causing the precipitation of feldspar from solution in the carbonaceous oozes on the lake or sea bottom. The randon arrangement of albite without reference to the bedding planes or lamination suggests that the enlargement of the feldspars occurred after deposition. Had enlargement occurred prior to or during deposition, it would be expected that the crystals would have tended to align themselves with the long diagonal of (010) parallel to the lamination. Such is not the case.

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DECEMBER, 1950

2304

ANNOUNCEMENT

SEDIMENTOLOGICAL CONGRESS IN THE NETHERLANDS
July 5–13, 1951

A committee of Dutch geologists and sedimentologists has planned a congress which is to be held in the Netherlands from July 5 to 13, 1951. The organizing committee consists of:

Dr. D. J. Doeglas, Chairman
Dr. R. D. Crommelin, General Secretary
L. A. AE. van Eerde, Treasurer
Dr. Tj. H. van Andel, Secretary of the Redaction Committee
Prof. Dr. C. H. Edelman
Prof. Dr. Ph. H. Kuenen
Dr. L. M. J. U. van Straaten

The organizing committee thinks it advisable to restrict the subjects of the present congress to sedimentology in its broadest sense, e.g., methods of investigation and results of studies from all periods, problems of erosion, transport, sedimentation, and diagenesis.

The congress will be held in Groningen and Wageningen from July 5th until 13th, 1951. Three days will be devoted to conferences and six days to excursions. The basic principle of the excursions will be to show the variations in structure and texture of sediments in various environments.

There will be excursions to the tidal flat area and its hinterland in the north of the province of Groningen, the bottom of the Zuiderzee and the Ijssel delta in the northeast Polder, active and poised braided river deposits near Arnhem and Nijmegen, the subenvironments of the meandering river in the center of Holland, and finally a boat trip along the river and estuary from fesh to salt water showing recent deposits.

It should be noted that probably on the 3d and 4th of July pre-excursions will be held to the peat-region of western Holland. These excursions, however, are entirely separate and do not belong officially to the congress.

The papers presented should not have been published before. The subjects are limited to studies of sedimentology. Manuscripts should preferably not exceed 15 doublespaced typewritten pages (figures not included) of quarto size with a front margin of 2 inches. Longer papers may be accepted under special circumstances. The author, however, should consult the Secretary of the Redaction Committee. The inclusion of an informative abstract of less than a half typewritten page is requested.

The official languages of the congress are English, French, and German and only papers in these languages are acceptable.

The proceedings will be printed *before* the congress. It therefore would be highly appreciated if manuscripts could be submitted as soon as possible. The closing date for acceptance of papers is February 1, 1951.

Manuscripts should be sent to the Secretary of the Redaction Committee, Dr. Tj. van Andel, Kon./Shell Laboratorium, Amsterdam-Noord, Holland.

The exact total price for the congress, excursions, and proceedings cannot be fixed so far in advance. The amount, however, will not exceed 200 Dutch Guilders (Amer. $55.00, Eng. £19/-/). Statement of participation should be sent to the General Secretary of the Sedimentological Congress, Duivendaal 2, Wageningen, Holland.

R. D. CROMMELIN

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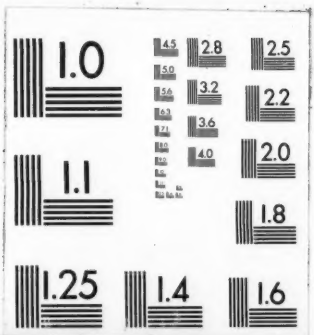
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